Interagency Ecological Program for the San Francisco Estuary

IEP NEWSLETTER

VOLUME 26, NUMBER 4, 2013

Of Interest to Managers

Gonzalo Castillo (USFWS), gonzalo_castillo@fws.gov, Matthew Dekar (USFWS), matthew_dekar@fws.gov, Joseph Kirsh (USFWS), joseph_kirsh@fws.gov, Lori Smith (USFWS), lori_smith@fws.gov, Zachary Jackson (USFWS), zachary_jackson@fws.gov

The 20 mm survey supplies near real-time catch data to limit the risk of Delta Smelt (*Hypomesus transpacificus*) entrainment during water exports. **Lauren Damon** (DFW) reported the 2013 results of the 20 mm Survey which monitors the distribution and relative abundance of larval and juvenile Delta Smelt. The 2013 index was 7.8, a decrease from 2012, and is similar to the indices from the early POD years (2001-2004). Delta Smelt in year 2013 reached a mean size of 20 mm earlier than in any previous years since the inception of this survey in 1995.

The CVPIA objective of a sustained increase in the number of age-15 White Sturgeon (*Acipenser transmontanus*) to 11,000 has not been achieved nearly two decades after being established. **Marty Gingras** and **Jason DuBois** (DFW) evaluated White Sturgeon abundance by age and recommended that progress toward CVPIA's recovery goal of white sturgeon be monitored using harvest rate from mark-recapture and harvest records from report cards. This method can be developed more quickly and data are deemed more precise and accurate than routine mark-recapture estimates. In addition, lengths from report cards are likely representative of the true length distribution as virtually all age-15 white sturgeon are 117-168 cm TL. The likely conditions required to improve the potential of achieving the CVPIA objective are further discussed.

Time series of year-class strength indices are required for effective management of White Sturgeon, its fishery, and its habitat. **Marty Gingras**, **Jason DuBois** and **Maxfield Fish** (DFW), investigated the utility of a year-class index based on catch-per-unit-effort (YCI_{BS}) and compared it to a year-class strength index based on Bay Study otter trawl (YCI_{Ep}) and to another index derived from the estimated salvage of White Sturgeon entrained at the State Water Project Skinner Fish Protective Facility (WST_{SAL}). The YCI_{BS} and YCI_{Ep} were highly correlated and were deemed complementary as White Sturgeon patchiness could affect either or both year-class strength indices. In contrast, WST_{SAL} was less correlated to the previously referred indices and was not considered an index of White Sturgeon year-class strength.

An abundance estimate of White Sturgeon is one of the metrics developed from the sturgeon mark-recapture study which was initiated in the San Francisco Estuary by the DFW in 1954. **Jason DuBois** and **Marty Gingras** reported additional methods to calculate sturgeon catch per unit effort (CPUE) from Commercial Passenger Fishing Vessel (CPFV) data and White Sturgeon CPUE from catch during tagging for the mark-recapture study. Trends in selected CPFV CPUE permutations for sturgeon and CPUE for White Sturgeon from tagging were generally similar. The CPFV CPUE for sturgeon varied substantially and did not vary monotonically with the tagging CPUE for White Sturgeon. Yet, a similar trend was tracked by some permutations of tagging CPUE, system-wide CPFV CPUE, and Suisun Bay CPFV CPUE. Hence, they were considered complementary "caveated indices" of system-wide White Sturgeon abundance.

The Zooplankton Study conducted by the DFW has provided abundance estimates of zooplankton in the upper San Francisco Estuary since 1972, including several introduced species which have become dominant in the upper estuary. **April Hennessy** and **Tina Enderlein** (DFW) reported the seasonal densities and trends of zooplankton sampled through the year 2012. After supplanting the introduced *Limnoithona sinensis* in 1993, the introduced *L. tetraspina* became the numerically dominant copepod in the upper estuary and in 2012 it was common throughout the sampling area and most abundant May through November in Suisun Bay, Suisun Marsh, and the lower Sacramento River. However, the abundance of the introduced calanoid copepod *Eurytemora affinis* has decreased since 2011. The introduced freshwater calanoid copepod *Pseudodiaptomus forbesi* was again the most abundant calanoid copepod in the study area for the third consecutive year in 2012. The abundance of the calanoid copepod *Acartia* spp. increased since 2011 as expected from their distribution in the lower estuary. In 2012, cladocerans were common throughout the year in the lower Sacramento and San Joaquin Rivers and their delta. The abundance of a native rotifer, *Synchaeta bicornis*, increased slightly in spring 2012, but decreased in summer and fall, consistent with its long term decline. Summer and fall abundance of the introduced mysid *Hyperacanthomysis longirostris* increased in 2012, after decreasing in 2011 to the lowest summer abundance since its introduction. In 2012, *Neomysis mercedis* was the least abundant of the common mysids in the sampling area across all months for the third consecutive year. The status of additional mysids and a possible introduction are also discussed.

In response to the rapid population decline of Delta Smelt, a refuge population was initiated in 2008 at the University of California, Davis. The refuge reached its sixth generation in 2013 and continued to be genetically managed and monitored with the goal of maintaining a captive population genetically similar to the wild population. **Tewdros Ghebremariam** (UC Davis Fish Conservation and Culture Lab) and colleagues reported a total of 2,217 individuals from the F_5 generation and wild were tagged in 2013. A tagging strategy of 1:2 female to male ratio was adopted as more males would create a more diverse gene pool for mating and potentially improve recovery of families. A pair cross or Full Sibling Group (FSG) is considered "recovered" if one or more tagged offspring are identified by genetic analysis in the following year. In an effort to keep the cultured stock more diverse, a tradeoff between wild stock and cultured stock resulted in a lower recovery of F_5 FSGs that were spawned in 2013. The lower recovery between wild x wild and cultured crosses may be the result of domestication selection. However, the genetic integrity of the Delta Smelt refuge population, as determined through neutral loci, has been maintained and is expected to continue through the next spawning season.

Did you know that quarterly highlights about current IEP science can be found on the IEP webpage along with a new calendar that displays IEP Project Work Team and other IEP-related public meetings? To view these features see the links below:

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Article Submission Deadlines for Calendar Year 2014

Issue	Article Submission Deadline
Issue 1 (Winter)	January 17, 2014
Issue 2 (Spring)	April 25, 2014
Issue 3 (Summer)	June 27, 2014
Issue 4 (Fall)	September 26, 2014

Submit articles to Shaun Philippart.

Contributed Papers

2013 20 mm Survey

Lauren Damon (DFW), lauren.damon@wildlife.ca.gov

California Department of Fish and Wildlife (DFW) staff conduct the 20 mm Survey annually to monitor the distribution and relative abundance of larval and juvenile Delta Smelt (*Hypomesus transpacificus*) in the upper San Francisco Estuary. The survey began in 1995 and supplies near real-time catch data to water and fisheries managers as part of an adaptive management strategy to limit the risk of Delta Smelt entrainment during water exports.

From March to July of 2013, DFW staff completed 9 bi-weekly surveys. A total of 47 stations (i.e. a full survey, Figure 1) were sampled each survey to measure larval fish and zooplankton densities. Surveys 1, 3, and 9 were incomplete, only 46 stations were sampled. Larval fish were collected using a conical net with 1600-micron mesh. The 20 mm net is 5.1 meters long with a mouth area of 1.51 square meters and is attached to a rigid steel D-ring frame that is mounted on skis. At each station, the entire water column was sampled using 3 stepped-oblique tows and a single zooplankton tow. All samples were preserved in 10% buffered formalin dyed with Rose Bengal for later identification in the laboratory.

A total of 111,120 fish (39 taxa) were collected in 2013. Pacific Herring (*Clupea pallasi*), Longfin Smelt (*Spirinchus thaleichthys*), and gobies (*Tridentiger* spp.) were the 3 most-abundant taxa, making up 86% of the total catch (Table 1). Delta Smelt was the 9th-most abundant species, making up about 1% of the total catch. Larval and juvenile Delta Smelt catches were low in March, likely due to the 20 mm net's inability to efficiently capture newly-hatched larvae (< 10 mm), but increased and remained consistent from April through June. The highest Delta Smelt catch occurred in early June (Survey 7), when 274 fish were caught with a mean length of 27.8 mm. Delta Smelt catch dropped off in the next survey and remained low for the final survey in July. This is a normal catch pattern attributable to late-in-season mortalities of larval fish and larger juveniles not efficiently retained in the net (Figure 2).

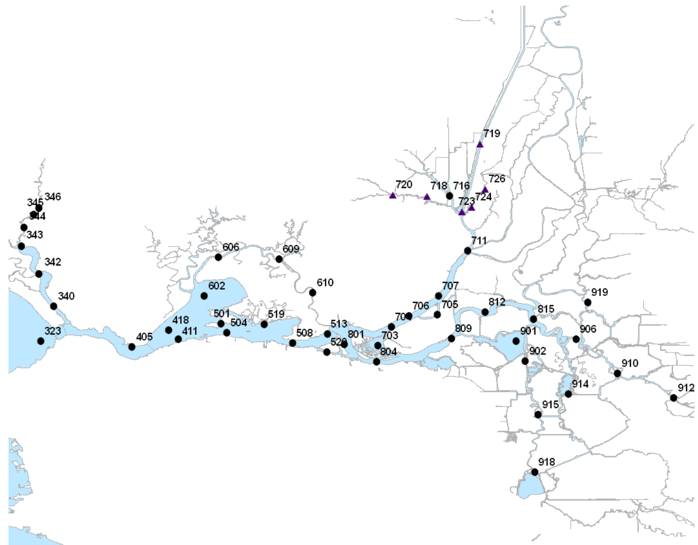

Figure 1 The CDFW 20 mm Survey stations, showing current sampling locations in the upper San Francisco Estuary. Stations marked with a black dot are core stations. Stations marked with a purple triangle are non-core stations.

The first Delta Smelt larvae were caught at the end of March (Survey 2) and ranged in size from 5 to 15 millimeters, indicating that spawning began very early in March as water temperatures reached 12 °C. Larvae were mainly distributed around the confluence and north Delta (Cache Slough and the Sacramento Deep Water Ship Channel) throughout the season, with a presence in the south and central Delta. In June, Delta Smelt (size range 14 – 40 mm FL) became present in Montezuma Slough and absent in the south and central Delta as temperature in that region surpassed 23 °C. As water temperature approaches 25 °C, predicted Delta Smelt occurrences have been reported to decline greatly in the 20 mm Survey (Gleason et al. 2007; Sommer and Mejia 2013) and the Summer Tow Net Survey (Nobriga et al. 2008). Larval Delta Smelt were present in areas where ripe and spent adult females were previously collected during the 2013 Spring Kodiak Trawl, indicating spawning likely occurred in those locations. The last newly-hatched larvae were caught in early May, indicating an end to the spawning season (Figure 2).

Table 1 Total species caught from the 2013 CDFW 20 mm Survey. "Unid" refers to individuals that were identified to the family level only.

Common Name	***Number***	***% Catch***
Pacific Herring	43,742	39.36%
Longfin Smelt	42,580	38.32%
Tidentiger spp.	9,336	8.40%
Threadfin Shad	4,001	3.60%
Striped Bass	3,369	3.03%
Yellowfin Goby	2,615	2.35%
Northern Anchovy	1,378	1.24%
Prickly Sculpin	1,136	1.02%
Delta Smelt (YOY)	1,126	1.01%
American Shad	426	0.38%
Bay Goby	420	0.38%
Three Spine Stickleback	369	0.33%
Jacksmelt	168	0.15%
Arrow Goby	109	0.10%
Cheekspot Goby	74	0.07%
Wakasagi	42	0.04%
Centrachids (Unid)	41	0.04%
Inland Silverside	27	0.02%
Bigscale Logperch	23	0.02%
White Catfish	21	0.02%
English Sole	18	0.02%
Chinook Salmon	16	0.01%
Bay Pipefish	13	0.01%
Longjaw Mudsucker	12	0.01%
Delta Smelt (Adults)	8	0.01%
Shimofuri Goby	8	0.01%
Channel Catfish	6	0.01%
Cyprinids (Unid)	5	<.01%
Pacific Staghorn Sculpin	5	<.01%
Largemouth Bass	5	<.01%
Carp	4	<.01%
Tule Perch	4	<.01%
Splittail	3	<.01%
Topsmelt	2	<.01%
Black Crappie	2	<.01%
Speckled Sanddab	2	<.01%
Brown Rockfish	1	<.01%
Sacramento Sucker	1	<.01%
Mosquitofish	1	<.01%
Bluegill Sunfish	1	<.01%

An index of Delta Smelt abundance for the 20 mm survey is calculated by DFW using data from the 4 surveys around which the mean size of the young of the year (YOY) Delta Smelt is 20 mm. The index is calculated using only the 41 stations (so-called 'core' stations; Figure 1) which have been sampled consistently since the survey's inception in 1995. The 2013 index is 7.8 (Figure 3) and was calculated using Surveys 3 (April) through 6 (May). This year was the earliest that Delta Smelt reached a mean size of 20 mm in the history of this survey. The 2013 index was a decrease from 2012, but still shows an upward trend since the 2007 drop-off and is similar to the indices from the early POD years (2001-2004).

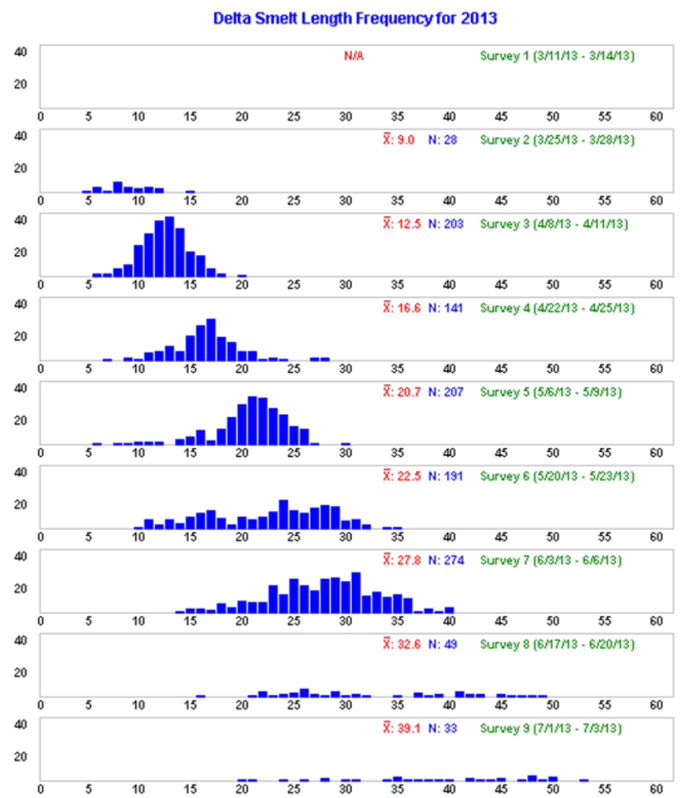

Figure 2 Frequency distributions of Delta Smelt length (mm) from CDFW's 2013 20 mm Survey (http://dfg.ca.gov/delta/data/20mm/Length_frequency.asp)

Delta Smelt were not widely distributed in 2013 and were concentrated in just a few portions of the estuary, mainly the confluence and north Delta (Figure 4). This distribution is likely due to the season's overall hydrology, where (1) X2 fluctuated at or above the confluence from early April through the end of the survey season (SWG 2013; see "Notes" for data download URL), and (2) the 2013 Sacramento Valley Water Year type is dry (see "Notes" for report URL) and Delta Smelt tend to spawn and rear upstream in drier water years (Wang 2007).

Year	Index
1995	4.4
1996	33.9
1997	19.3
1998	7.7
1999	39.7
2000	23.8
2001	11.3
2002	8.0
2003	13.1
2004	8.2
2005	15.4
2006	9.9
2007	1.0
2008	2.9
2009	2.3
2010	3.8
2011	8.0
2012	11.1
2013	7.8

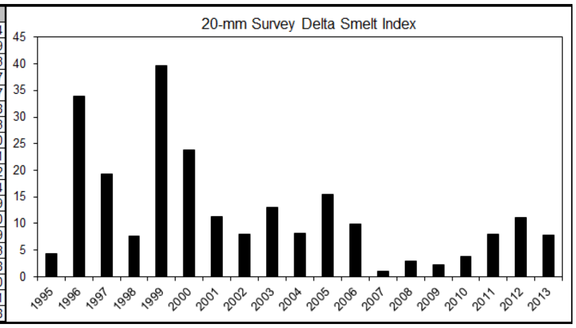

Figure 3 Time series of YOY Delta Smelt relative abundance by year from the CDFW 20 mm Survey

Fish distribution maps, length distributions, and catch per unit effort (CPUE) by station for the current year are reported on the 20 mm Survey webpage (http://dfg.ca.gov/delta/projects.asp?ProjectID=20mm). Existing data and metadata can be found at our FTP site (ftp://ftp.dfg.ca.gov/Delta%20Smelt/) and detailed methods on the calculation of the 20 mm abundance index are available through this author.

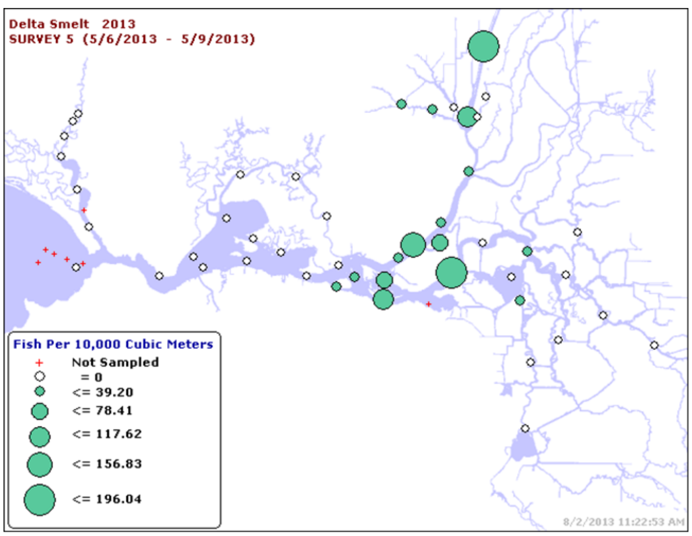

Figure 4 Delta Smelt distribution map from CDFW 20 mm Survey 5 (taken from http://dfg.ca.gov/delta/projects.asp?ProjectID=20mm). Green bubbles represent the relative abundance of YOY Delta Smelt at each site (see legend). White bubbles are sampled stations with no YOY Delta Smelt caught. Red crosses indicate the station was not sampled (not part of current routine survey).

Notes

Water Year Index (preliminary 08/01/2013) from http://cdec.water.ca.gov/cgi-progs/reports/EXECSUM

X2 data from cdec.water.ca.gov/ (station CX2)

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Monitoring Progress Toward a CVPIA Recovery Objective: Estimating White Sturgeon Abundance by Age

Marty Gingras (DFW), marty.gingras@wildlife.ca.gov and Jason DuBois (DFW), jason.dubois@wildlife.ca.gov

Introduction

The Central Valley Project Improvement Act (CVPIA) objective of a sustained increase in the number of age-15 White Sturgeon to 11,000 is the only quantitative management objective for White Sturgeon in California. The California Department of Fish and Wildlife monitors progress toward the objective by using routine abundance estimates from a mark-recapture study and — because routine aging of sturgeon has not been funded — an age-length key is used to assign ages to fish captured during tagging. We have previously described the routine abundance estimates as coming from a complicated algorithm that includes periodic updates with recapture data collected up to several years after tagging, assumptions about growth rate and about mortality attributable to tagging, and more professional judgment than we would like (DuBois and others 2011).

In an effort to speed the production of abundance estimates and perhaps improve the accuracy of abundance estimates, we have been and are taking a number of steps. One key step was development of an alternative method of estimating the abundance of legally-harvestable White Sturgeon (DuBois and Gingras 2011) that uses estimates of harvest rate, uses harvest data from Sturgeon Fishing Report Cards (Report Cards), and can be finalized relatively quickly. White Sturgeon 117-168 cm Total Length (TL, i.e., 46-66" TL) were legal to harvest February 28, 2007–December 31, 2012.

Another key step is assessing the degree to which the age-specific abundance estimates are biased due to size selectivity of the (trammel) nets used to capture fish during tagging, when and where tagging occurs, and how many fish are sampled. The nets have been standardized for many years and include panels of 3 different mesh sizes (DuBois and others 2012), and tagging occurs August-October in San Pablo Bay and/or Suisun Bay. It is plausible the length distribution of fish caught during tagging is not representative of the true length distribution of the population, and if so the age-specific abundance estimates made using the age-length key are inaccurate and possibly biased.

Here we compare and contrast age-specific estimates of 117-168 cm TL (i.e., 46-66" TL) White Sturgeon abundance using length frequency data from tagging and from Report Cards, the alternative method of abundance estimation, and an age-length key. Anglers are required by CCR Title 14 Sections 5.79 and 27.92 to report lengths of harvested White Sturgeon on Report Cards and to submit Report Cards by January 31 of the following year. Use of the length dataset from Report Cards for the present purpose is intuitively appealing because it contains more White Sturgeon lengths per year than the tagging dataset and any other dataset.

Table 1 White Sturgeon age-length key (data in Kohlhorst and others 1980); note: matrix within dashed border contains data on fish within legal slot limit; ages 0-6 and bins 21-95 cm TL omitted for formatting purposes (values represent proportions)

Bins	*White Sturgeon Ages*															
(cm TL)	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*
96-100	0.2568	0.3108	0.2838	0.0811	0.0135	0	0	0	0	0	0	0	0	0	0	0
101-105	0.2281	0.1842	0.307	0.1579	0.0702	0	0	0	0	0	0	0	0	0	0	0
106-110	0.0571	0.2143	0.3	0.2429	0.1	0.0286	0.0286	0	0	0	0	0	0	0	0	0
111-115	0	0.1186	0.3051	0.4237	0.1017	0.0169	0.0339	0	0	0	0	0	0	0	0	0
116-120	0	0.1136	0.1818	0.1818	0.1591	0.1591	0.0455	0.0909	0.0455	0.0227	0	0	0	0	0	0
121-125	0	0	0.0833	0.1111	0.1944	0.1389	0.1389	0.1389	0.1667	0.0278	0	0	0	0	0	0
126-130	0	0	0.0541	0.0811	0.2162	0.1351	0.0541	0.1622	0.0541	0.0811	0.0811	0.027	0.027	0.027	0	0
131-135	0	0	0	0.0882	0.1176	0.1471	0.1176	0.0294	0.1176	0.1471	0.1176	0.0294	0	0.0882	0	0
136-140	0	0	0	0	0	0.1154	0	0.2308	0.1538	0.2308	0.1538	0.0385	0.0769	0	0	0
141-145	0	0	0	0	0	0.0286	0.0571	0.1429	0.1429	0.2286	0.1714	0.1143	0	0.0857	0.0286	0
146-150	0	0	0	0	0	0.027	0.1081	0.1622	0.1622	0.1351	0.0541	0.1892	0.1622	0	0	0
151-155	0	0	0	0	0	0	0.0435	0.1304	0.087	0.087	0.1304	0.3478	0	0.087	0.087	0
156-160	0	0	0	0	0	0	0	0.0769	0.0769	0.1538	0.0769	0.1538	0.0769	0.3077	0	0.0769
161-165	0	0	0	0	0	0	0	0	0	0.25	0.1667	0.1667	0.0833	0.1667	0.1667	0
166-170	0	0	0	0	0	0	0	0	0	0.125	0	0.125	0.5	0.25	0	0
171-175	0	0	0	0	0	0	0	0	0	0.125	0.25	0.25	0.375	0	0	0
176-180	0	0	0	0	0	0	0	0	0	0	0	0.1667	0.1667	0.3333	0.1667	0.1667
181-185	0	0	0	0	0	0	0	0	0	0	0	0.3333	0	0.3333	0	0.3333
>185	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0.25

Investigation

We used lengths and abundance estimates for the years 2007-2011. The abundance estimates are for fish 117-168 cm TL (Range: ~35,000-57,000 fish) and were calculated using harvest records (Report Card data) and harvest rates (mark-recapture data; DuBois and Gingras 2011). Lengths are those reported by anglers as from fish they kept (N = 8,491) and fish 117-168 cm TL caught during tagging for the Department's mark-recapture study (N = 1,518).

Table 2 White Sturgeon abundance estimates by age (8-21) using Report Card data and tagging data (years 2007-2011)

Age	*Report Card*					*Tagging*				
	2007	*2008*	*2009*	*2010*	*2011*	*2007*	*2008*	*2009*	*2010*	*2011*
8	724	394	573	373	487	867	682	964	375	559
9	2,212	1,380	1,770	1,193	1,588	2,600	2,045	2,411	1,313	1,863
10	3,218	2,094	2,593	1,789	2,459	3,611	2,727	3,375	2,063	2,795
11	4,867	3,277	3,965	2,734	3,817	5,633	4,091	4,822	3,001	4,286
12	4,947	3,425	4,014	2,908	4,226	5,489	3,955	4,983	3,189	4,472
13	3,379	2,587	2,942	2,162	3,099	3,756	2,864	3,215	2,251	3,541
14	6,435	4,928	5,386	4,150	6,250	6,789	4,909	5,625	4,127	6,149
15	5,591	4,361	4,688	3,653	5,430	5,922	4,227	4,983	3,752	5,590
16	7,240	5,766	5,760	4,622	7,018	6,645	5,045	5,143	4,502	6,522
17	4,987	3,942	4,014	3,181	4,892	4,333	3,409	3,536	3,001	4,659
18	4,987	4,337	4,264	3,330	5,200	4,189	3,545	2,732	3,001	4,845
19	2,655	2,341	1,970	1,740	2,587	2,744	2,318	1,607	1,688	2,422
20	3,982	3,376	2,917	2,435	3,612	3,322	3,000	2,089	2,251	3,354
21	1,408	1,158	1,072	795	1,229	867	682	482	563	932

We calculated each estimate of annual age-specific abundance using the age-length key (Table 1) and the following algorithm: (1) Bin the lengths, then (2) multiply the number of fish per bin by the historic fraction of the age distribution from that bin and sum (column-wise) those products, then (3) divide the number of fish at each age by the total number of fish lengths, and then (4) multiply the estimates of White Sturgeon 117-168 cm TL abundance by the fraction of fish at each age. The historic fraction of age at length is from data in Kohlhorst and others (1980).

Estimated abundance of cohorts using length frequency data from tagging and from Report Cards is notably low (range 373-7240; Avg 3330) and — due to recruitment to and from the 117-168 cm TL length range as well as relative imprecision of the estimates — does not clearly show the expected reduction in abundance of each cohort attributable to natural mortality and harvest (Table 2). Note from Table 1 that all or nearly all fish aged 12-16 are 117-168 cm TL and accounted for in these estimates of abundance.

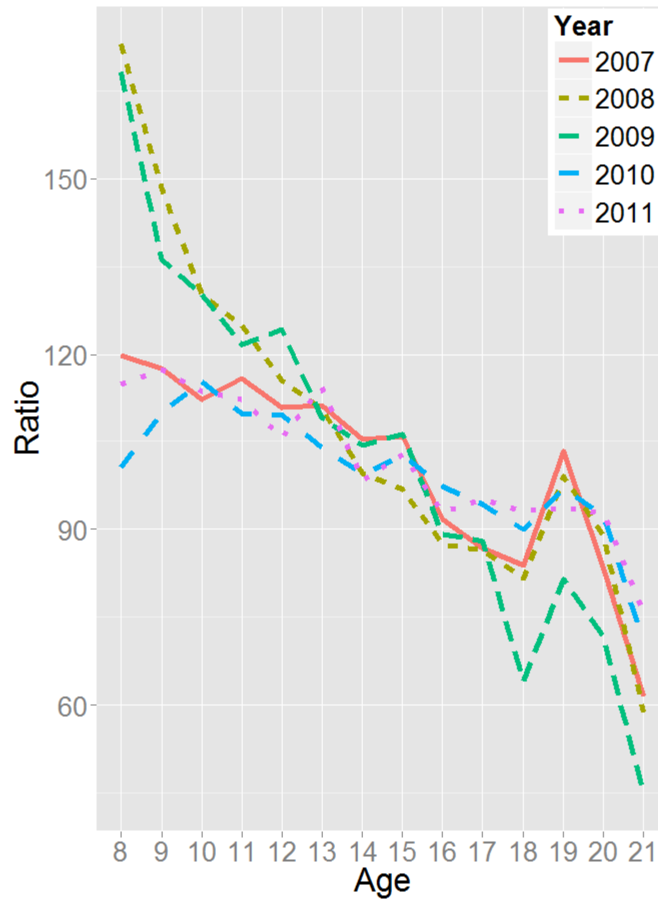

Figure 1 Ratio (tagging data/Card data) of White Sturgeon estimates (years 2007-2011) at age (8-21)

Annual estimates of abundance for each brood year using length frequency data from Report Cards and from tagging are strongly correlated (*r* range: 0.895-0.988; average: 0.953) and linear with slopes slightly less than 1 (range 0.8323-0.9833; average 0.935). The slopes suggest that one of the sets of length data is biased.

The ratio between abundance estimates for each age using the two sets of length data (e.g., 867 age-8 fish in 2007 from tagging divided by 724 age-8 fish in 2007 from Report Cards) ranged between 0.45-1.73% (average:

1.02%). Declining trends in ratio with age are typical and the greatest differences in ratio occur among estimates for relatively young fish and for relatively old fish (Figure 1). The slopes suggest that one of the sets of length data is biased, and the range of ratios per age suggests similar distributions of lengths near the middle of the length range in both datasets.

Discussion

From our brief investigation, it is clear that the selection of length frequency distribution is important when using length frequencies to estimate the age-specific abundance of White Sturgeon.

Length frequency distributions from Report Cards are affected by whatever selectivity anglers apply (e.g., hook size; 'high grading' through catch-and-release), but we suspect and have been repeatedly told by anglers that selectivity is low because the legal size limit is narrow (presently 40-60 inches Fork Length) and catch rates are low (e.g., < 3 fish per 100 hours effort; DuBois and others 2011). We suspect that abundance estimates made using lengths from Report Cards are more accurate than those made using lengths from tagging, because anglers fish throughout the year and throughout the range of White Sturgeon, use a variety of angling techniques, and use a variety of angling gear — whereas catch during tagging is substantially constrained by season, location, and gear requirements.

Estimates of 117-168 cm TL White Sturgeon abundance using harvest rate (from mark-recapture) and harvest records (from Report Cards) can be developed more quickly and are more precise than routine mark-recapture estimates, lengths from Report Cards are likely representative of the true length distribution, and essentially all age-15 White Sturgeon are 117-168 cm TL. For those reasons, we recommend that progress toward CVPIA's recovery goal of 11,000 age-15 White Sturgeon be monitored using those data and that approach.

NOTE TO MANAGERS: The CVPIA objective of a sustained increase in the number of age-15 White Sturgeon to 11,000 has not been achieved approximately 2 decades after being established (DuBois and Gingras 2011). From our work here on the estimation of White Sturgeon abundance, from work to index young-of-the-year White Sturgeon abundance (Fish 2010; CDFW 2013), and from work to relate the relative abundance of White Sturgeon to Sacramento-San Joaquin Delta outflow (Fish 2010), it is likely that the number of age-15 White Sturgeon will not increase to 11,000 for at least another 5 years and it is nearly certain that there will be no sustained increase in the number of age-15 White Sturgeon without substantial reduction of harvest, hatchery augmentation, major improvement in fish passage (e.g., re-watering the San Joaquin; dam removal), and/or beneficial climate change.

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Further Investigations into San Francisco Estuary White Sturgeon (*Acipenser transmontanus*) Year-Class Strength

Marty Gingras (DFW), marty.gingras@wildlife.ca.gov, Jason DuBois (DFW), jason.dubois@wildlife.ca.gov, Max Fish (DFW), max.fish@wildlife.ca.gov

Introduction

Successful management of White Sturgeon, its fishery, and its habitat requires a time series of year-class strength indices. Indices of White Sturgeon year-class strength from observations of very young fish avoid most of the inaccuracies and expenses associated with assignment of ages to older fish through examination of hard parts and provide upwards of 10 years advance notice of recruitment to the fishery. Fish (2010) reported the relation between Sacramento-San Joaquin Delta (Delta) outflow and a year-class index (YCI_{BS}) from catch-per-unit-effort (CPUE) of age-0 and age-1 White Sturgeon collected systematically by the San Francisco Bay Study's otter trawl from throughout much of the area young White Sturgeon occur, and suggested that the metric was of more utility than preceding indices and certain categories of alternative indices. Here we describe a brief investigation intended to help understand YCI_{BS} and some other potential White Sturgeon year-class strength indices.

Methods

We contrasted YCI_{BS} with a possible index (YCI_{Ep}; as in Counihan et al. 1999) from collection of White Sturgeon by Bay Study otter trawl and with a possible index (WST_{SAL}) derived from the estimated salvage of White Sturgeon entrained at the State Water Project (SWP) Skinner Fish Protective Facility in the South Delta. The contrasts we describe are from comparing plots of WST_{SAL}, YCI_{BS}, and YCI_{Ep} as time series and from the linear regression statistics (R statistical software Version 2.15.2, 2012) coefficient of determination (as R^2) and p-value. We also investigated possible indices from catch of White Sturgeon reported by the recreational anglers who submitted Sturgeon Fishing Report Cards and catch by the Department using experimental setlines (DuBois et al. 2010), but — largely because those time series are so brief — we found them to be of little use and they will not be described here.

E_p is the annual percentage of Bay Study otter trawls in which age-0 or age-1 White Sturgeon were collected. YCI_{Ep} is an annual metric based on E_p, is calculated using only the original 35 Bay Study stations, and is the sum of the percentage of total otter trawl tows which contained at least one age-0 White Sturgeon (April-October) and the percentage of total otter trawl tows which contained at least one age-1 White Sturgeon (February-October) lagged by one year:

$$YCI_{EP_t} = [E_p(\text{Apr-Oct})]_t + [E_p(\text{Feb-Oct})]_{t+1}$$

We investigated the use of estimated salvage to index White Sturgeon year-class strength because the estimates vary substantially year to year and it seems that more young White Sturgeon are salvaged than are documented anywhere else in the system. Estimated salvage at the SWP is an extrapolation from the number of fish collected at the Skinner Fish Facility during exports and — due in large part to variations in sampling effort, sampling efficiency, and water operations (e.g., exports and operation of the Delta Cross Channel) — is not itself a plausible index of White Sturgeon year-class strength. WST_{SAL} is White Sturgeon density at the SWP from estimated salvage relative to the volume of water exported, and is more likely to vary in proportion to White Sturgeon year-class strength than estimated salvage. WST_{SAL} is calculated using the following formula:

$$WST_{SAL} = \sum_{\text{May}-\text{December}} \left(\left[\frac{\sum_m \text{Salvage}}{(\sum_m \text{Acre Feet}) \times 1233.48} \right] \times 10{,}000 \right)$$

where:

Salvage = expanded salvage of White Sturgeon
Acre Feet = volume of water pumped
m = individual month (May through December only)
1233.48 = factor to convert acre feet to cubic meters
10,000 = factor to convert density to per 10,000 cm

Although White Sturgeon larvae and juveniles are salvaged at the SWP, estimates of White Sturgeon salvage, and thus salvage density, are not stratified by fish length or age. In an effort to assure that WST_{SAL} represents White Sturgeon production each year rather than production over the course of more than one year, annual WST_{SAL} values only include densities for the May-December period when age-0 White Sturgeon were likely the dominant age-class salvaged.

Results

Trends in YCI_{BS} and YCI_{Ep} were nearly identical (Figure 1, Table 1). The relationship between the two metrics was strongly linear (Test for zero slope: $F = 419.2$; $DF = 1.30$; $p < 0.001$; $R^2 = 0.933$). With few exceptions, juvenile White Sturgeon were relatively abundant only in years classified as wet.

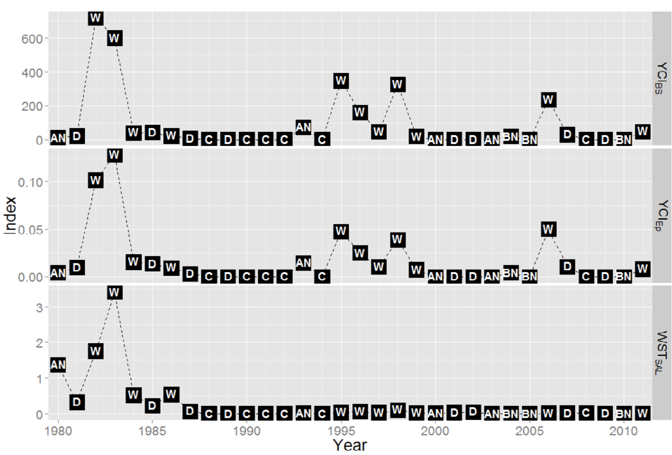

Figure 1 Time series from 1980 to 2011 of year-class strength indices for White Sturgeon from Bay Study (YCI_{BS} and YCI_{Ep}) and White Sturgeon density at the SWP (WST_{SAL}). Data points labeled with water-year type, see Table 1 for water-year type descriptions.

Trends in YCI_{BS} and WST_{SAL} share some attributes — e.g., record-high numbers of White Sturgeon in the same years; long periods when few if any young White Sturgeon were observed (Figure 1, Table 1) — but the relationship cannot be reasonably described by a simple model. A linear fit resulted only because both variables were exceptionally high in 1982 and 1983 (Test for zero slope: $F = 30.12$; $DF = 1.30$; $p < 0.001$; $R^2 = 0.501$), and in absence of values from 1982 and 1983 there are hints of a weak inverse relationship. As with YCI_{BS} and YCI_{Ep}, with few exceptions juvenile White Sturgeon appeared relatively abundant only in years classified as wet.

Table 1 Annual White Sturgeon year-class strength indices from Bay Study (YCI_{BS} and YCI_{Ep}) and estimated salvage density (WST_{SAL}). Water-year type included for reader's reference, for further details refer to Fish (2010).

Year	*Water Year*[a]	*YCI_{BS}*	*YCI_{EP}*	*WST_{SAL}*
1980	AN	11.076	0.004	1.373
1981	D	21.848	0.010	0.330
1982	W	719.697	0.102	1.760
1983	W	599.637	0.128	3.425
1984	W	40.657	0.016	0.526
1985	D	44.039	0.014	0.225
1986	W	23.503	0.010	0.548
1987	D	8.466	0.003	0.075
1988	C	0	0	0
1989	D	0	0	0
1990	C	0	0	0
1991	C	0	0	0
1992	C	0	0	0
1993	AN	72.494	0.015	0.013
1994	C	0	0	0
1995	W	348.611	0.048	0.042
1996	W	160.999	0.025	0.069
1997	W	46.733	0.010	0.034
1998	W	327.740	0.039	0.109
1999	W	18.190	0.007	0.023
2000	AN	0	0	0.011
2001	D	0	0	0.027
2002	D	0	0	0.057
2003	AN	0	0	0
2004	BN	19.131	0.004	0
2005	BN	0	0	0
2006	W	234.599	0.050	0.010
2007	D	30.192	0.011	0.018
2008	C	0	0	0.022
2009	D	0	0	0.005
2010	BN	0	0	0
2011	W	48.806	0.008	0.003

[a] AN = above normal, BN = below normal, C = critical, D = dry, W = wet

Discussion

Although both YCI_{BS} and YCI_{Ep} were calculated using the same Bay Study survey data, their strong correlation was not inevitable and suggests that observed White Sturgeon spatial patchiness did not necessarily affect the accuracy of either. We consider these two measures complementary rather than alternatives, because future White Sturgeon patchiness could affect either or both year-class strength indices.

Use of WST_{SAL} to index White Sturgeon year-class strength would be inherently suspect for the same reasons that salvage is not a plausible index (e.g., variations in sampling effort and water operations) and because most young White Sturgeon — by virtue of the distribution of adults during spawning (see DuBois et al. 2010) and behavior of young White Sturgeon — likely moved along the bottom (Kynard and Parker 2005) down the Sacramento River rather than into the south Delta (as in Stevens and Miller 1970) where they might be salvaged. Thus, given that annual trends in YCI_{BS} (and the closely-related YCI_{Ep}) and WST_{SAL} are only coarsely similar, we do not consider WST_{SAL} an index of White Sturgeon year-class strength but will consider WST_{SAL} when assessing annual White Sturgeon year-class strength.

Having explored potential year-class indices from the pertinent surveys we are aware of, we plan to gain additional insight into YCI_{BS} and YCI_{Ep} — and White Sturgeon year-class strength in general — by mining data that speaks to the phenology of White Sturgeon spawning and age-0 recruitment to the Delta and bays of the San Francisco Estuary. Our hope is that we will reduce uncertainty about White Sturgeon year-class strength and learn more about environmental factors influencing White Sturgeon year-class strength (as in Coutant 2004, Fish 2010, Mayfield and Cech 2004, and McAdam et al. 2005).

Management Note: The University of California at Davis (UCD) and commercial aquaculture facilities produced and released White Sturgeon fry and fingerlings from 1980-1988 as mitigation for collection of broodstock, but survival of the stocked fish was not evaluated. Although we have not yet found detailed records of the dates, locations, sizes, or numbers of released fish, we have recently learned that UCD released roughly 200,000 fingerlings in the spring of 1982 (Monaco 1983) and UCD was reported to have released a total of 500,000 fish by 1986 (Steinhart 1986). We are looking into whether or not it is plausible that record-high 1982 and 1983 White Sturgeon YCI_{BS}, YCI_{Ep}, and WST_{SAL} values were notably affected by stocked fish.

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Sturgeon CPUE from Commercial Passenger Fishing Vessels and White Sturgeon CPUE from a Mark-Recapture Study

Jason DuBois (DFW), jason.dubois@wildlife.ca.gov and Marty Gingras (DFW), marty.gingras@wildlife.ca.gov

Introduction

The California Department of Fish and Wildlife (CDFW) began conducting a mark-recapture study of San Francisco Estuary sturgeon in 1954 and estimated White Sturgeon (*Acipenser transmontanus*) abundance is one of many metrics developed from the data. Because the estimates are available for 25 years, can take years to finalize, and are often quite imprecise, we sought to develop one or more catch per unit effort (CPUE) abundance indices that could be produced annually, quickly, and allow for more-timely dissemination of trend information. We have recently explored several ways to calculate sturgeon CPUE from Commercial Passenger Fishing Vessel (CPFV) data and White Sturgeon CPUE from catch during tagging for the CDFW mark-recapture study. This article is a brief summary of comparisons between and among those metrics, and is primarily intended to identify nuances in the data and caveats to interpretation of the indices.

White Sturgeon CPUE from tagging for the mark-recapture study is straightforward to calculate and we routinely publish it in Field Season Summary reports (e.g., DuBois and Harris 2013). However — because the mark-recapture study has only deployed trammel nets in San Pablo Bay and/or Suisun Bay during August, September and October — CPUE from tagging might not index system-wide trends in annual abundance. Interpretation of the White Sturgeon CPUE time series is complicated somewhat because prior to 1990 the nets were composed only of 8” stretched-mesh panels and were composed of 6”, 7”, and 8” stretched-mesh panels thereafter.

Operators of CPFVs are paid to help passengers target and catch a fish species of interest (e.g., White Sturgeon), and CPFV operators are required to complete and submit to the CDFW a log for each trip. It is possible to calculate CPUE from log data, because each log contains information on catch by species (or species aggregations), number of anglers, time fished, and date fished, as well as the location (called “blocks”) where most fish were caught during the trip (Hill and Schneider 1999). Interpretation of a sturgeon CPFV CPUE time series is somewhat confounded because logs contain no length data and because size limits on White Sturgeon since 1980 changed from ≥ 102, 107-183, 112-183, 117-183, and 117-168 cm Total Length (DuBois and others 2012). Furthermore, CPFV sturgeon catch as of 2012 had not been identified to species and CPUE calculated from data prior to March 2007 — when it became illegal to take Green Sturgeon — almost certainly includes catch of White Sturgeon and a relatively few Green Sturgeon whereas thereafter likely includes nearly no Green Sturgeon.

Investigation

We only used CPFV data from 1980-2012, because log data prior to 1980 is now only available as monthly summaries (Hill and Schneider 1999) and thus it is impossible to calculate species-specific effort from that portion of the dataset. We calculated annual CPFV CPUE (per Equation 1, where t = year) based on the following criteria: catch (i.e., at least 1 sturgeon noted; kept fish; kept fish plus released fish) and fishing location (i.e., “blocks,” Table 1), as well as on whether or not CPFVs targeted sturgeon and sturgeon fate (i.e., harvested or released; Table 1). Some of these CPUE “permutations” use nearly the same data. When making pair-wise comparisons of 12 CPFV CPUE permutations by way of scatter plots (e.g., see the upper-most 7 rows of Figure 1 for examples of comparisons), we found that the relations often vary substantially. For example, 11 of 66 comparisons had R^2 values > 0.50 (range 0.52-0.99; avg 0.73) and several of those are notably attributable to an apparent outlier (Suisun Bay in 1998).

$$CPUE_t = \left[\frac{\sum catch_t}{\sum anglerhours_t}\right] \times 100 \qquad \text{Equation 1}$$

We calculated annual White Sturgeon CPUE from tagging per Equation 1, except that effort was in terms of net-fathom-hours rather than angler-hours, then made pair-wise comparisons of 12 CPFV CPUE permutations to two permutations of tagging CPUE (e.g., see the lower-most 2 rows of Figure 1 for examples of comparisons).

Two of 24 comparisons had R^2 values > 0.50 (range 0.58-0.70; avg 0.64). Tagging CPUE was most similar to CPFV CPUE when considering fish legal-sized during tagging relative to trips targeting sturgeon in Suisun Bay and system-wide, but was only slightly less similar when considering all trips. Use of fish fate (e.g., kept fish plus released fish) did not usually improve the relation between CPFV CPUE and tagging CPUE.

Table 1 Description of criteria used for sturgeon and White Sturgeon CPUE permutations

CPUE Permutation	*Criteria Used for Calculating CPUE*
suc.stu.sfe	successful trips only; kept only; no target; all blocks east of Golden Gate Bridge
all.stu.sfe	all trips; kept only; no target; all blocks east of Golden Gate Bridge
all.targ.stu.sfe	all trips; kept only; target sturgeon; all blocks east of Golden Gate Bridge
all.kept.rel.sfe	all trips; kept + released; no target; all blocks east of Golden Gate Bridge
suc.stu.spb	successful trips only; kept only; no target; only block 301 (San Pablo Bay)
all.stu.spb	all trips; kept only; no target; only block 301 (San Pablo Bay)
all.targ.stu.spb	all trips; kept only; target sturgeon; only block 301 (San Pablo Bay)
all.kept.rel.spb	all trips; kept + released; no target; only block 301 (San Pablo Bay)
suc.stu.sb	successful trips only; kept only; no target; only blocks 302 and 308 (Suisun Bay)
all.stu.sb	all trips; kept only; no target; only blocks 302 and 308 (Suisun Bay)
all.targ.stu.sb	all trips; kept only; target sturgeon; only blocks 302 and 308 (Suisun Bay)
all.kept.rel.sb	all trips; kept + released; no target; only blocks 302 and 308 (Suisun Bay)
tag.all.stu	white sturgeon caught during tagging, regardless of size (length)
tag.legal.stu	white sturgeon caught during tagging legal-sized at time of capture

Successful trips includes trips where catch (as kept only) ≥ 1
All trips includes trips where catch (as kept or as kept + released) ≥ 0
Kept only means catch includes only number of kept sturgeon
Kept + released means catch includes number of kept + released sturgeon
No target means vessel did not specifically target sturgeon

Annual effort for each CPFV CPUE permutation varied from zero (just 4 instances) to 26,108 hours (avg 7,728 hours), which suggests that relatively few of the CPFV CPUE values are substantially influenced by outliers attributable to relatively little fishing effort. We also noted that the time series of annual effort for several CPFV CPUE permutations (Figure 2) reflects the general trends in CPUE, suggesting that the CPFV fishery responds strongly to variations in CPUE.

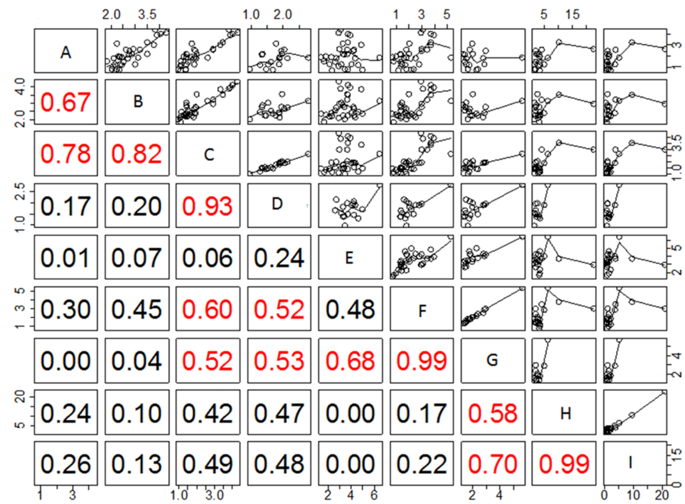

Figure 1 Scatter plot matrix comparing various CPFV CPUE for sturgeon and CPUE for White Sturgeon caught during tagging (Table 1); upper panels with loess line, and R^2 in lower panels (values in red > 0.5). A: all.stu.spb, B: suc.stu.sfe, C: all.stu.sfe, D: all.targ.stu.sfe, E: suc.stu.sb, F: all.stu.sb, G: all.targ.stu.sb, H: tag.all.stu, I: tag.legal.stu.

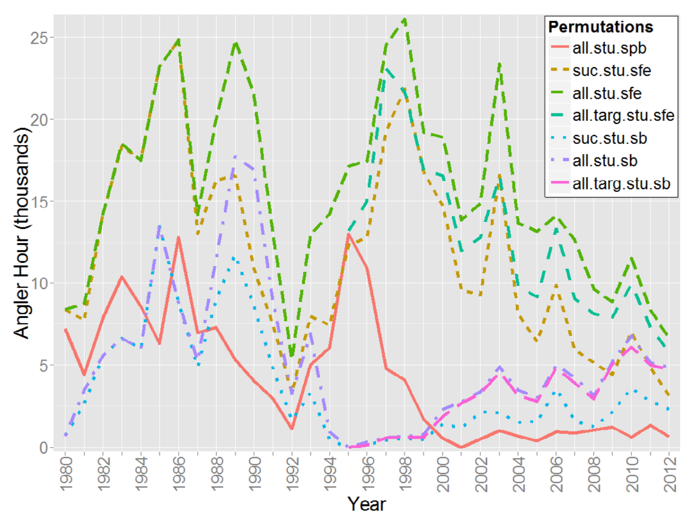

Figure 2 Time series (1980-2012) of effort (as angler-hours) from CPFVs for various permutations (Table 1)

Trends in CPFV CPUE for sturgeon and CPUE for White Sturgeon from tagging are generally similar (Figure 3). The trends include variations that correspond to the recruitment and subsequent decline of strong year-classes that (a) must have been produced during 1969-1975 when most years were classified as wet (see Kohlhorst 1980 for evidence regarding 1969 and 1970), (b) were produced during some wet years in the early 1980s (Kohlhorst and others 1991) and were augmented by hatchery production (Monaco 1983; Steinhart 1986), and (c) were produced in the mid-to-late 1990s (Fish 2010).

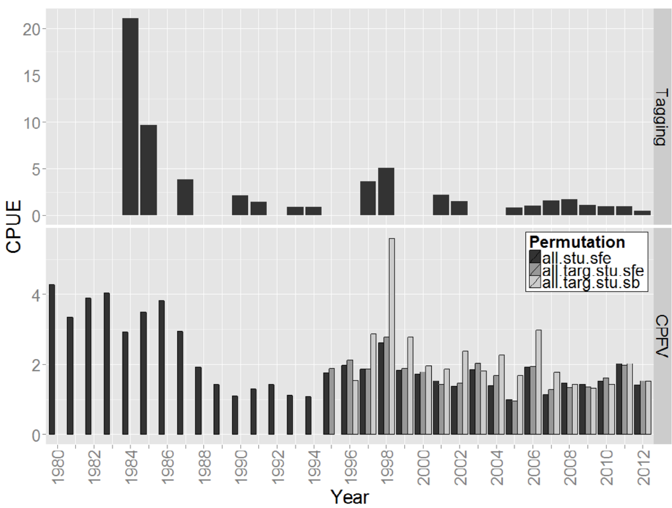

Figure 3 Time series (1980-2012) of tagging CPUE (tag.legal.stu; as catch per 100 net-fathom-hours; top figure) and of CPFV CPUE (as catch per 100 angler-hours; bottom figure) for select permutations (Table 1)

Discussion

The CPFV CPUE for sturgeon varied substantially (e.g., by location and angler motivation) and did not vary monotonically with CPUE for White Sturgeon from tagging. However, a similar trend was tracked by some permutations of tagging CPUE, system-wide CPFV CPUE, and Suisun Bay CPFV CPUE — and from that we consider those as complementary 'caveated indices' of system-wide White Sturgeon abundance.

The best relations between tagging and CPFV CPUE came from data that has been required of CPFVs only since 1995. For that reason and because in 2011 and again in 2013 the CDFW instructed CPFV operators to identify sturgeon to species, we expect stronger relations between tagging and CPFV CPUE in the future.

We attribute the extremely large CPUE values from the mark-recapture study in 1984 and 1985 to unusual distributions of fish rather than rapid changes in the system-wide abundance of fish or bias attributable to mesh size. In hopes of learning more about White Sturgeon distributions and ecology (e.g., responses to Sacramento-San Joaquin Delta outflow), we plan to look into those 1984 and 1985 tagging CPUE outliers as well as the CPFV CPUE outlier from Suisun Bay in 1998.

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Zooplankton Monitoring 2012

April Hennessy (DFW), april.hennessy@wildlife.ca.gov, and Tina Enderlein (DFW), tina.enderlein@wildlife.ca.gov

Introduction

The Zooplankton Study has provided abundance estimates of zooplankton taxa in the upper San Francisco Estuary since 1972 to assess trends in fish food resources. The study also assists with detection and monitoring of zooplankton recently introduced to the estuary. Three gear types are used: 1) a pump for sampling microzooplankton < 1.0 mm long, including rotifers, copepod nauplii, and adult copepods of the genus *Limnoithona*; 2) a modified Clarke-Bumpus (CB) net for sampling mesozooplankton 0.5-3.0 mm long, including cladocerans, copepodids (immature copepods), and adult copepods; and 3) a macrozooplankton net for sampling zooplankton 1-20 mm long, which targets mysid shrimp. Here seasonal abundance indices are presented from 1974 through 2012 for the most common copepods, cladocerans, rotifers, and mysids.

Methods

During 2012, sampling occurred monthly from January through December at 22 stations, including 12 core stations (i.e., stations sampled consistently since study inception in 1972) and 2 floating entrapment zone stations (referred to as EZ stations) located at bottom electrical conductivity of 2 and 6 mS/cm (approximately 1 and 3 ‰). The study area extends from eastern San Pablo Bay through the Sacramento-San Joaquin-Delta (Delta, see station map at www.dfg.ca.gov/delta/data/zooplankton/stations.asp). Seasonal indices presented here were calculated using 16 stations: the 12 core stations, the 2 EZ stations, and 2 additional stations sampled consistently since 1974 (Suisun Slough station S42 and Disappointment Slough station M10). Reports published prior to 2007 used data from 1972 and included only the 12 core and 2 EZ stations. This report includes data from 2 additional stations; therefore indices start in 1974 and may be slightly different from those reported prior to 2007. However, overall trends remained the same.

Data were grouped into 3 seasons: 1) spring, March through May, 2) summer, June through August, and 3) fall, September through November. January, February, and December were not always sampled historically and therefore not used for long-term trend analyses. Abundance indices were calculated as the mean number of each taxon per cubic meter of water sampled (reported as catch-per-unit effort, CPUE) by gear, season, and year for the 16 stations. Relative calanoid copepod abundance for each season of 2012, including winter (December 2011 through February 2012), used data from all stations sampled. Similar to the 2004 through 2011 Status and Trends reports, indices were separated by gear type and taxon, whereas pre-2004 reports combined CB and pump data for each taxon into a single index. Abundance indices are reported from the gear type that most effectively captures each taxon.

Copepods

Both congeners of the cyclopoid copepod genus *Limnoithona* have been introduced and inhabit the upper estuary: *L. sinensis*, first recorded by this study in 1979 (Ferrari and Orsi 1984), and *L. tetraspina*, first recorded by this study in 1993 (Orsi and Ohtsuka 1999). In 1993, *L. tetraspina* mostly supplanted the historically common and slightly larger *L. sinensis*, and numerically became the dominant copepod in the upper estuary. *L. tetraspina* is common in both brackish and freshwater. As an ambush predator that feeds on motile prey (Bouley and Kimmerer 2006), *L. tetraspina* may have benefited from the phytoplankton species composition change described by Brown (2009) from non-motile diatoms to motile flagellates. Despite high densities of *L. tetraspina* in the estuary, it may not be a readily available food source for visual predators, like Delta Smelt, due to its small size and relatively motionless behavior in the water column (Bouley and Kimmerer 2006).

Abundance indices for the two species of *Limnoithona* are reported as one genus, since they were not always identified and enumerated separately. However, since most of the *Limnoithona* spp. are *L. tetraspina* here we will discuss this taxon as *L. tetraspina*. Additionally, both pump and CB net indices are presented because *L. tetraspina* is not completely retained by the CB net, especially in summer and fall when adults are smaller. In each season of 2012, the abundance of *L. tetraspina* increased in pump samples, and decreased in CB samples (Figures 1A, 1B, and 1C). In 2012, spring and summer pump abundance were the highest since 2008, and fall pump abundance was the highest on record (Figures 1A, 1B, and 1C). Although *L. tetraspina* CB abundance decreased in 2012 from 2011, spring and fall abundance decreased only slightly and were amongst the highest on record (Figures 1A and 1C). Summer *L. tetraspina* CB abundance decreased dramatically and was the lowest since 2001(Figure 1B). Higher 2012 pump abundance and lower CB abundance indicated that the majority of *L. tetraspina* individuals were smaller and therefore not retained as well by the CB net. *L. tetraspina* was common throughout the sampling area in 2012, and was most abundant May through November in Suisun Bay, Suisun Marsh, and the lower Sacramento River. The highest densities of *L. tetraspina* occurred during June in Suisun Marsh in Montezuma Slough (109,992 m^{-3}), and during July in eastern Suisun Bay (107,110 m^{-3}). *L. sinensis* continued to be collected in low numbers in 2012, and was most abundant in the eastern Delta from late summer through fall.

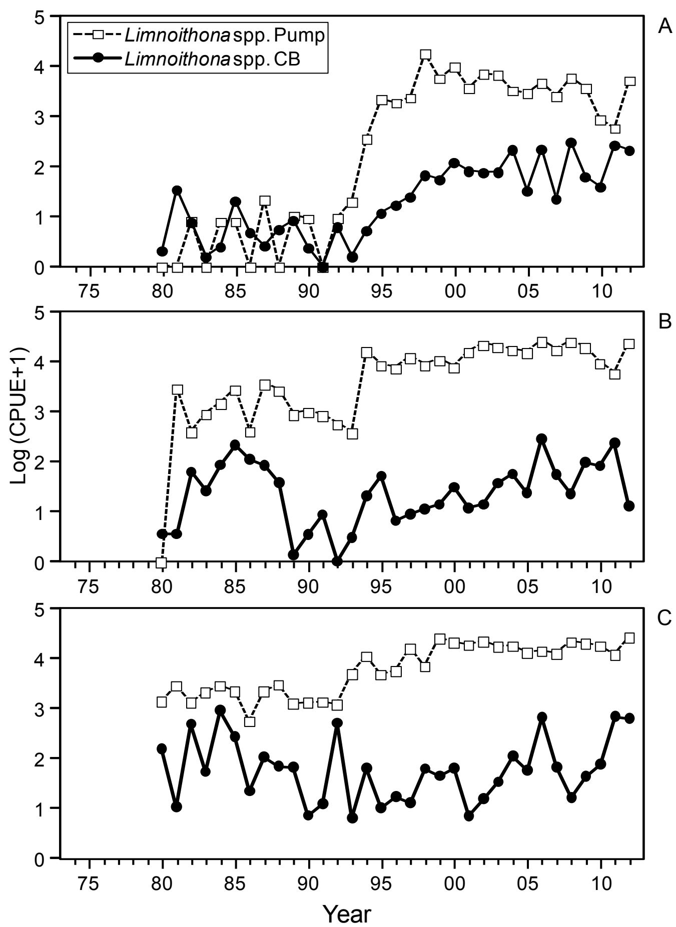

Figure 1 Abundance of *Limnoithona* spp. (Log_{10} of mean catch*m^{-3} + 1) from the pump and Clarke-Bumpus net in spring (A), summer (B), and fall (C), 1974 – 2012

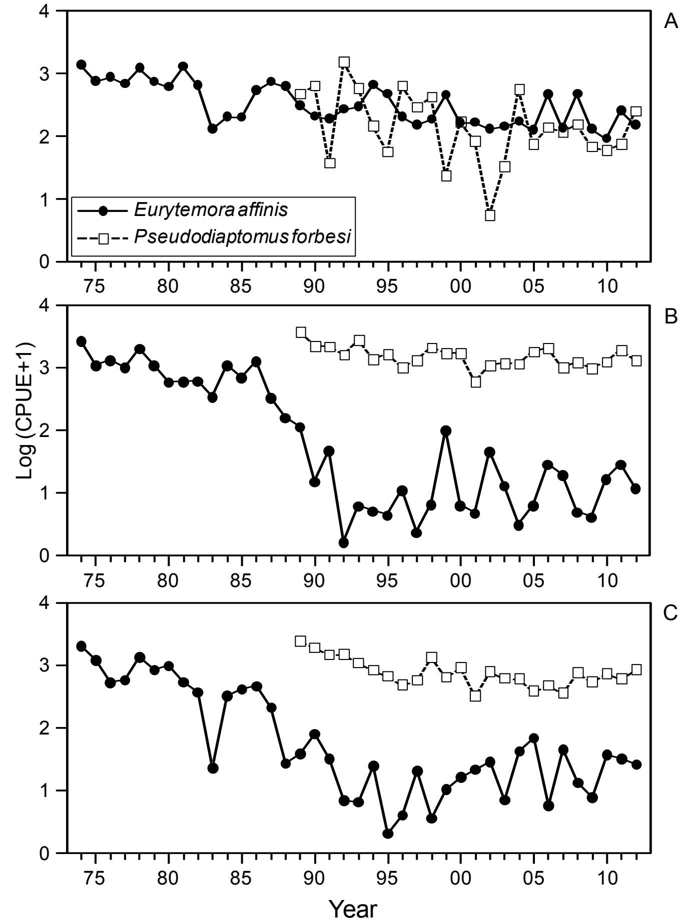

Figure 2 Abundance of *Eurytemora affinis* and *Pseudodiaptomus forbesi* (Log_{10} of mean catch*m^{-3} + 1) from the Clarke-Bumpus net in spring (A), summer (B), and fall (C), 1974 – 2012

Eurytemora affinis, a calanoid copepod introduced to the estuary before monitoring began, was once a major food source for larval and juvenile fishes of many species and also adult planktivores, such as Delta Smelt and Threadfin Shad. It is found throughout the upper estuary in every season and is most abundant in salinities less than 6 ‰. *E. affinis* abundance declined in all seasons (Figures 2A, 2B, and 2C) since monitoring began, with the sharpest downturns during summer and fall of the late-1980s (Figures 2B and 2C), subsequent to the introductions of the overbite clam, *Potamocorbula amurensis*, and the calanoid copepod *Pseudodiaptomus forbesi*. Prior to these introductions, *E. affinis* abundance was usually highest during summer; however, since 1987 its abundance has been highest in spring and dropped abruptly in summer, when both *P. forbesi* abundance and *P. amurensis* grazing rates increase. In 2012, *E. affinis* was again the fifth most abundant calanoid copepod in the study area based on annual mean CPUE, as it has been since 2008. Relative abundance of *E. affinis* was highest in spring when it accounted for 8% of the total calanoid copepod CPUE (Figure 3A). *E. affinis* abundance decreased in each season of 2012 from 2011 (Figures 2A, 2B, and 2C). Yet, spring abundance of *E. affinis* in 2012 was still higher than the lowest abundance on record in 2010 (Figure 2A). Summer *E. affinis* abundance also decreased in 2012, after a peak in 2011 that was the highest since 2006 (Figure 2B). Although fall abundance decreased slightly in 2012 for the second year in a row (Figure 2C), it was higher than the 1990 through 2011 mean. *E. affinis* was found in low numbers January through May in 2012, in all regions upstream of Carquinez Strait. Peak densities occurred in May (Figure 3B) in Suisun Marsh (989 m^{-3}), and in the eastern Delta in November (443 m^{-3}).

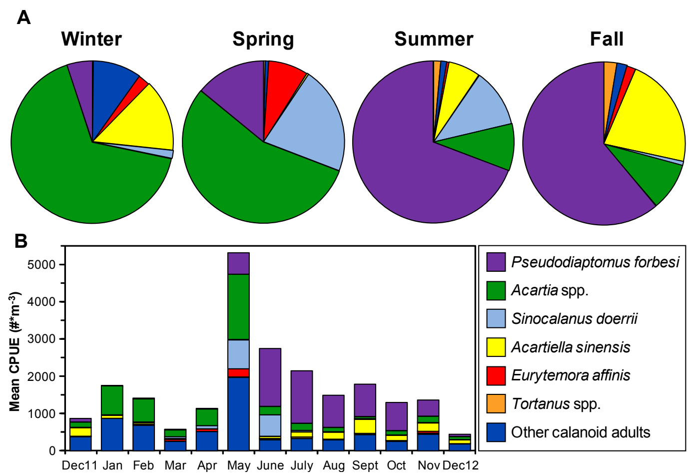

Figure 3 Relative abundance of the most common calanoid copepods in 2012 (percent mean catch*m^{-3}) from the Clarke-Bumpus net from all stations by seasons (A) and average monthly CPUE (B). Seasonal pie charts include winter (December 2011-February 2012), spring (March-May 2012), summer (June-August 2012), and fall (September-November 2012).

Pseudodiaptomus forbesi is an introduced freshwater calanoid copepod first detected by this study in the upper estuary in late October 1987 (Orsi and Walter 1991). By 1989, *P. forbesi* had become the most abundant copepod in summer and fall (Figures 2B and 2C). Although *P. forbesi* abundance declined slightly since its introduction, it remained relatively abundant in summer and fall compared to other copepods. In 2012, *P. forbesi* was again the most abundant calanoid copepod in the study area for the third year in a row, based on annual mean CPUE. Relative abundance peaked in summer when it accounted for 69% of the total calanoid copepod CPUE (Figure 3A). Spring abundance has always been highly variable and increased sharply in 2012 from 2011, to the highest since 2004 (Figure 2A). Summer abundance decreased slightly in 2012 from 2011, whereas fall abundance increased slightly from 2011 to the highest since 2000 (Figures 2B and 2C). During summer and fall 2012, *P. forbesi* was most abundant in the San Joaquin River, the Delta, and the lower Sacramento River. The highest density was in July in Frank's Tract in the south Delta, where CPUE was 6,754 m^{-3}.

Several species of the native calanoid copepod genus *Acartia* are abundant in San Pablo Bay and expand their range into Suisun Bay and the western Delta as salinity increases seasonally and annually. Conversely, their affinity for higher salinities is sufficiently strong that their distribution shifts seaward of the sampling area during high-outflow events, resulting in low seasonal and annual abundance. In 2012, *Acartia* spp. was the second most abundant calanoid copepod in the study area based on annual mean CPUE. Relative abundance peaked in winter, when *Acartia* spp. accounted for 67% of the total calanoid copepod CPUE (Figure 3A). *Acartia* spp. abundance increased in every season of 2012 from 2011 (Figures 4A, 4B, and 4C). Higher spring outflow in 2011 resulted in the lowest *Acartia* spp. abundance since 1996; however, lower outflow in spring 2012 resulted in increased abundance (Figure 4A). *Acartia* spp. abundance also increased in summer 2012, as expected in lower outflow years (Figure 4B). By fall 2012, *Acartia* spp. abundance increased from summer levels, but was only slightly higher than fall 2011 abundance (Figure 4C). In 2012, *Acartia* spp. was common throughout the year in San Pablo Bay and Carquinez Strait. The highest densities occurred in San Pablo Bay from January through July with a peak in May (16,846 m^{-3}) (Figure 3B).

Acartiella sinensis is an introduced calanoid copepod first recorded by this study in late 1993 (Orsi and Ohtsuka 1999), it is most abundant in the entrapment zone during summer and fall. In 2012, *A. sinensis* was the fourth most abundant calanoid copepod in the study area based on annual mean CPUE. Relative abundance was highest in fall, when it accounted for 22% of the total calanoid copepod CPUE (Figure 3A). In 2012, *A. sinensis* abundance decreased in spring, summer, and fall from 2011 (Figures 4A, 4B, and 4C). Spring abundance has always been highly variable; after declining steadily from 2004 through 2007 abundance increased from 2008 to 2011 before declining again in 2012 (Figure 4A). Summer *A. sinensis* abundance decreased in 2012 from its second highest abundance in 2011 (Figure 4B). Fall abundance has been relatively stable since 2001, and in 2012 decreased slightly to the lowest fall abundance since 2006 (Figure 4C). In 2012, *A. sinensis* abundance was highest late summer through fall in Suisun Bay, Suisun Marsh, and the lower Sacramento and San Joaquin Rivers. Peak densities occurred in the lower Sacramento River in September (1,793 m^{-3}) and November (1,702 m^{-3}) (Figure 3B).

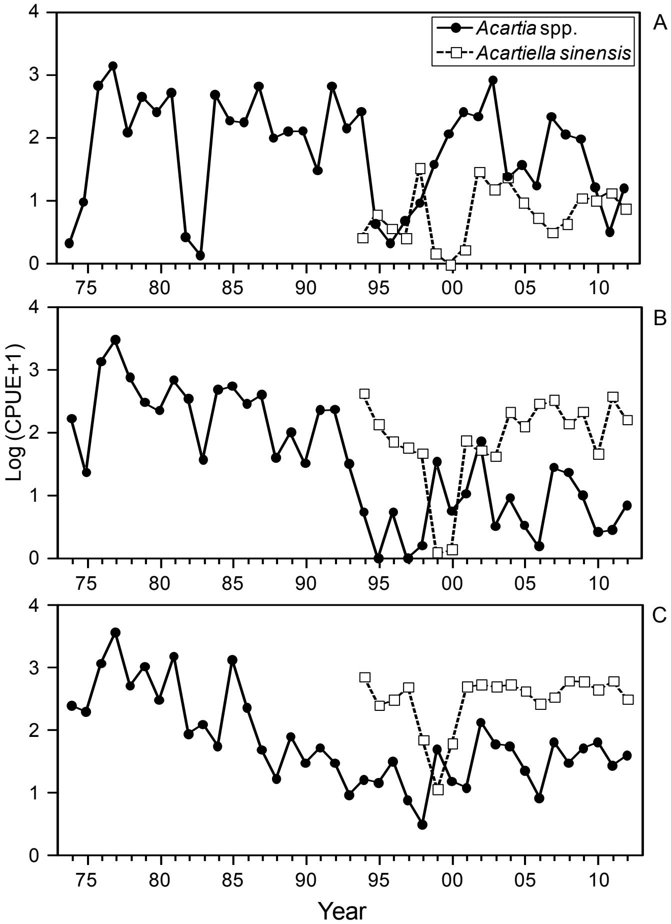

Figure 4 Abundance of *Acartia* spp. and *Acartiella sinensis* (Log_{10} of mean catch*m^{-3} + 1) from the Clarke-Bumpus net in spring (A), summer (B), and fall (C), 1974 – 2012

Sinocalanus doerrii, an introduced freshwater calanoid copepod, was first recorded by this study in late 1978 (Orsi et al. 1983). Initially most abundant in summer, *S. doerrii* abundance began to decline during summer and fall in the mid-1980s (Figures 5B and 5C). This downward trend continued through the mid-1990s, followed by modest increases recently. In 2012, *S. doerrii* was the third most abundant calanoid copepod based on annual mean CPUE. Relative abundance peaked in spring, when it accounted for 21% of the total calanoid copepod CPUE (Figure 3A). *S. doerrii* abundance increased in 2012 from 2011 in all seasons (Figure 5A, 5B, and 5C). After a decrease in 2011, spring abundance increased in 2012 to densities similar to 2008 through 2010 (Figure 5A). Summer abundance increased slightly in 2012 from 2011 (Figure 5B). Fall abundance also increased in 2012 from 2011, and was the highest since 2002 (Figure 5C). In 2012, *S. doerrii* was found throughout the year in the Delta and the lower Sacramento and San Joaquin Rivers. Peak densities occurred in May (Figure 3B) in Montezuma Slough (2,792 m^{-3}) and in June (Figure 3B) in the lower Sacramento River near Decker Island (2,292 m^{-3}).

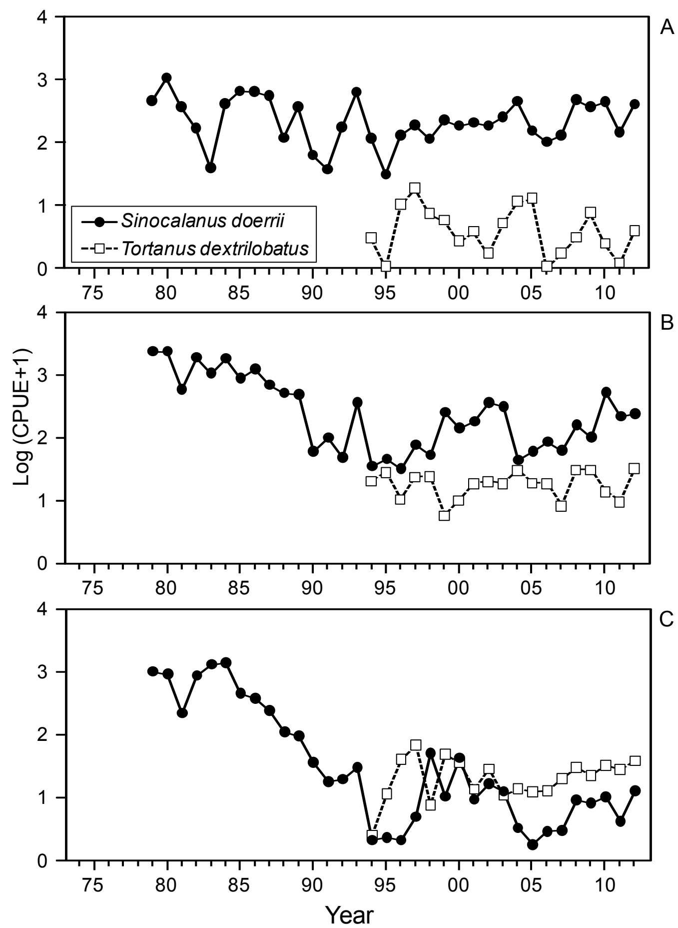

Figure 5 Abundance of *Sinocalanus doerrii* and *Tortanus dextrilobatus* (Log_{10} of mean catch*m^{-3} + 1) from the Clarke-Bumpus net in spring (A), summer (B), and fall (C), 1974 – 2012

Tortanus dextrilobatus is an introduced brackish-water calanoid copepod first recorded in summer 1993 (Orsi and Ohtsuka 1999). *T. dextrilobatus* is a large carnivorous copepod whose abundance increases in the sampling area as flows decrease and salinities increase during summer and fall. In 2012, *T. dextrilobatus* was again the least abundant of the common calanoid copepods in the study area. Relative abundance peaked in fall when it accounted for 3% of the total calanoid copepod CPUE (Figure 3A). *T. dextrilobatus* abundance increased in all seasons of 2012 from 2011 (Figures 5A, 5B, and 5C), as expected due to low freshwater outflow. After dropping sharply in 2010 and 2011, spring abundance increased in 2012 (Figure 5A). Summer abundance also declined in 2010 and 2011, but rebounded in 2012 to the highest summer abundance since *T. dextrilobatus* was introduced (Figure 5B). Despite small decreases in 2009 and 2011, fall 2012 abundance continued the steady increase that began in 2007 and reached the highest fall abundance since 1999 (Figure 5C). In 2012, *T. dextrilobatus* was found throughout most of the year in San Pablo Bay and Carquinez Strait, and in summer and fall in Suisun Bay and Suisun Marsh. Abundance peaked in September in Carquinez Strait (344 m^{-3}).

Cladocerans

Bosmina, *Daphnia*, and *Diaphanosoma* are the most abundant cladoceran genera in the upper estuary. Combined, these freshwater cladocerans had an overall downward trend since the early 1970s (Figure 6). After a peak in 2007, spring abundance began declining steadily and fell to the lowest on record in 2012 (Figure 6A). Although summer and fall abundance increased in 2012 from 2011, both remained below the seasonal means (Figures 6B and 6C). In 2012, cladocerans were common throughout the year in the Delta and the lower Sacramento and San Joaquin Rivers. Abundance was highest April through November in the eastern Delta, where the peak density occurred in Disappointment Slough in September (21,083 m^{-3}).

Rotifers

Synchaeta bicornis is a native brackish-water rotifer that is usually most abundant in the upper estuary in summer and fall, when salinity increases. However, the long-term abundance of *S. bicornis* has declined since the 1970s (Figures 7A, 7B, and 7C). *S. bicornis* abundance increased slightly in spring 2012 (Figure 7A), but decreased in summer and fall (Figures 7B, and 7C). From 2002 through 2007 there was no spring catch at any core stations, followed by an increase in 2008 and 2009 (Figure 7A). Higher spring outflow in 2010 again resulted in no *S. bicornis* catch at any stations sampled, and although spring abundance increased slightly in 2011 and 2012, it remained very low (Figure 7A). After a sharp increase in 2011 to the highest summer abundance since 1992, abundance decreased again in summer 2012 (Figure 7B). Fall 2012 abundance also decreased after reaching the third highest abundance on record in 2011, but remained much higher than fall abundance in other recent years (Figure 7C). In 2012, *S. bicornis* was most abundant August through October in Carquinez Strait and Suisun Bay, and in September and October in the lower Sacramento River, where density peaked in September (81,831 m^{-3}).

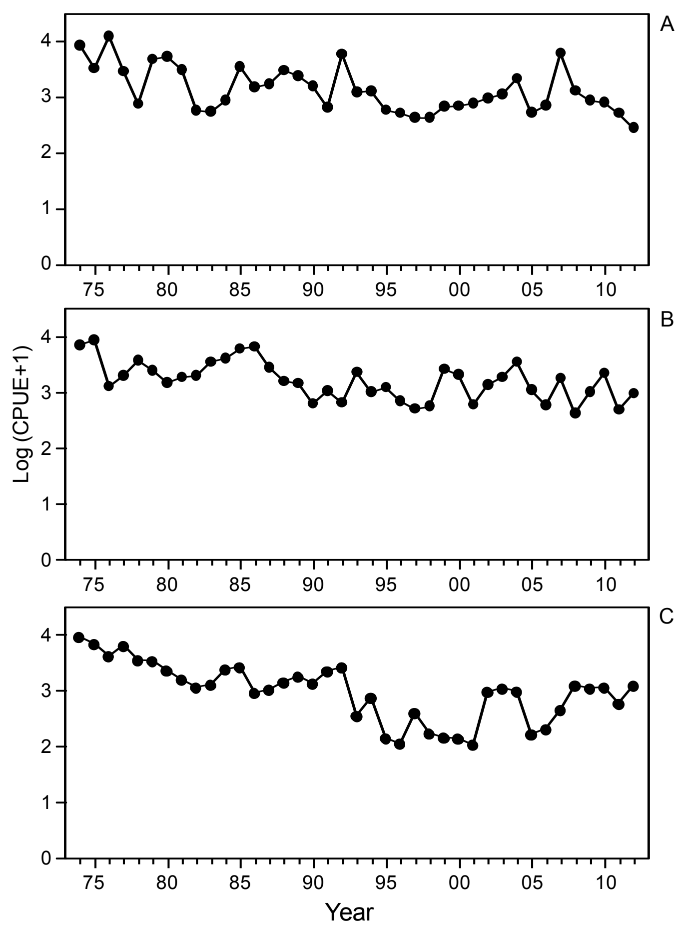

Figure 6 Abundance of Cladocera (Log_{10} of mean catch*m^{-3} + 1) from the Clarke-Bumpus net in spring (A), summer (B), and fall (C), 1974 – 2012

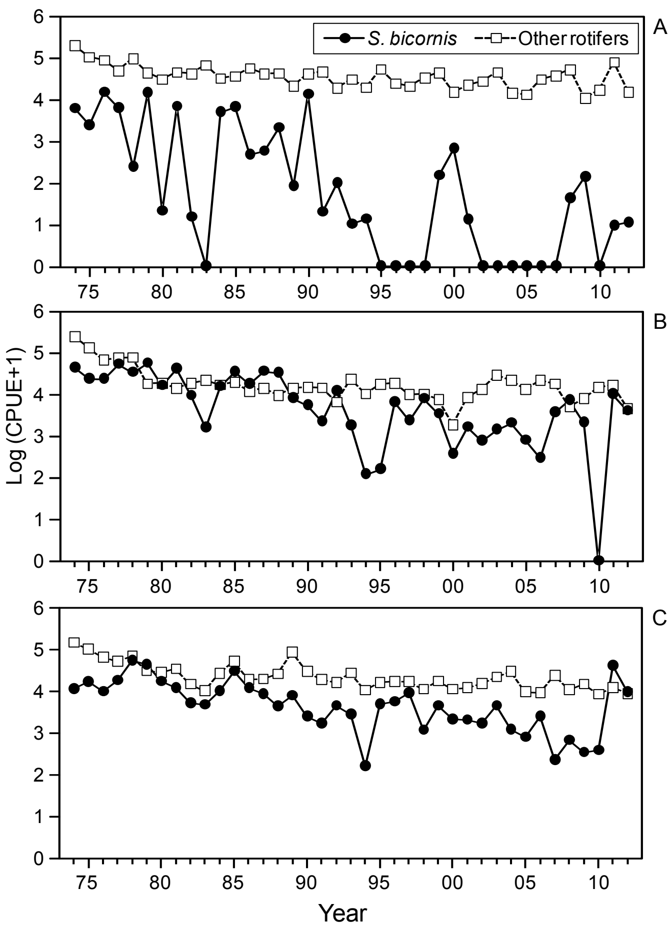

Figure 7 Abundance of *Synchaeta bicornis* and rotifers excluding *S. bicornis* (Log$_{10}$ of mean catch*m^{-3} + 1) from the pump in spring (A), summer (B), and fall (C), 1974 – 2012

Abundance of all other rotifers, without *S. bicornis*, declined from the early 1970s through the 1980s, but stabilized since the early 1990s (Figures 7A, 7B, and 7C). In 2012, rotifer abundance decreased in all seasons. After increasing to the highest spring abundance since 1978 in 2011, spring 2012 abundance decreased (Figure 7A). Summer abundance increased steadily from 2009 through 2011, but decreased again in 2012 to the lowest summer abundance since 2000 (Figure 7B). In 2012, fall abundance was the second lowest since the study began (Figure 7C). Rotifers were common throughout the study area in 2012, with the highest densities in the San Joaquin River near Stockton in January (320,128 m^{-3}) and April (230,661 m^{-3}), and in February in Suisun Marsh in Montezuma Slough (269,833 m^{-3}).

Mysids

Hyperacanthomysis longirostris (formerly Acanthomysis bowmani), an introduced mysid first collected by the study in summer 1993 (Modlin and Orsi 1997), has been the most abundant mysid in the upper estuary since summer 1995 (Table 1A). *H. longirostris* is commonly found in densities of more than 10 m^{-3}, and occasionally in densities of more than 100 m^{-3}. In 2012, *H. longirostris* abundance increased in each season from 2011(Table 1A). Spring *H. longirostris* abundance increased from 1995 to 1998 and fluctuated thereafter, but after decreasing in 2011 to the second lowest abundance on record, increased again in 2012. Summer abundance also increased in 2012, after decreasing in 2011 to the lowest summer abundance since its introduction. *H. longirostris* fall abundance declined consistently since 2004, resulting in record low abundances from 2007 through 2009 of less than 1 m^{-3}. Fall abundance increased in 2012 for the second year in a row, and was the highest fall abundance since 2004. During 2012, *H. longirostris* was most abundant in Suisun Bay in June and July, in Suisun Marsh in June, and in the entrapment zone in the lower Sacramento River in September. The highest 2012 densities occurred during June in eastern Suisun Bay (167 m^{-3}) and July in eastern Suisun Bay near the confluence of the Sacramento and San Joaquin Rivers (122 m^{-3}).

Neomysis mercedis, historically the only common mysid in the upper estuary, suffered a severe population crash in the early 1990s. In 2012, it was the least abundant of the common mysids in the sampling area across all months for the third consecutive year. *N. mercedis* is most abundant in spring and summer, and prior to the population crash mean spring and summer densities exceeded 50 m^{-3} (Table 1A). Since 1994, mean spring abundance has been less than 1 m^{-3}, rendering *N. mercedis* inconsequential as a food source in most open-water areas of the upper estuary. After some of the lowest spring densities on record from 2007 through 2010, abundance of *N. mercedis* increased in 2011 and was the highest since 2006, but decreased again in 2012. Summer abundance has been extremely low, less than 1 m^{-3}, since 1997. In 2012, summer abundance decreased from 2011, which was the highest summer abundance since 1996. Very few *N. mercedis* have been caught during fall in recent years; from 2005 through 2008 no *N. mercedis* were caught in fall, from 2009 through 2011 only 1 *N. mercedis* was caught during fall of each year, and in 2012 only 2 *N. mercedis* were caught during fall. Peak 2012 densities occurred in June in the lower Sacramento River near Decker Island (4 m^{-3}) and in the San Joaquin River near Stockton (1 m^{-3}).

Table 1A Seasonal abundance of the most common mysid species (mean catch*m^{-3}) from the macrozooplankton net. For brevity, 1974-1989 time period reported as one seasonal abundance (mean catch*m^{-3}).

Year	*Hyperacanthomysis longirostris*			*Neomysis mercedis*		
	Spring	*Summer*	*Fall*	*Spring*	*Summer*	*Fall*
1974-1989				54.506	87.293	18.154
1990				23.458	7.612	0.436
1991				32.058	18.331	0.489
1992				4.223	1.989	0.076
1993			2.470	7.850	22.503	0.008
1994	0.932	21.604	2.063	0.449	0.733	0.004
1995	0.437	7.180	4.407	0.590	0.370	0.000
1996	1.636	11.693	4.432	0.541	1.432	0.001
1997	6.939	27.630	7.714	0.565	0.063	0.000
1998	18.136	6.015	18.691	0.181	0.238	0.025
1999	3.888	34.697	14.329	0.264	0.288	0.001
2000	23.580	38.453	9.958	0.880	0.136	0.001
2001	4.767	13.441	8.956	0.422	0.052	0.001
2002	10.121	21.224	7.516	0.022	0.069	0.001
2003	4.342	21.307	4.555	0.022	0.046	< 0.001
2004	9.915	13.725	5.044	0.150	0.016	0.002
2005	4.010	16.281	3.334	0.092	0.141	0.000
2006	7.186	14.143	1.967	0.321	0.137	0.000
2007	0.969	8.997	0.575	0.005	0.023	0.000
2008	17.696	14.574	0.715	0.063	0.108	0.000
2009	0.729	6.303	0.681	0.016	0.013	< 0.001
2010	2.887	25.975	2.045	0.013	0.174	< 0.001
2011	0.584	4.350	2.815	0.161	0.313	< 0.001
2012	2.339	17.520	4.782	0.027	0.129	0.001
Average:	6.373	17.111	5.352	24.217	37.220	7.475

Neomysis kadiakensis is a native brackish-water mysid that regularly appeared in mysid samples beginning in 1996, but was not common until recently (Table 1B). From 2001 through 2008, *N. kadiakensis* was the second most abundant mysid in the study area, but from 2009 through 2012 fell to the third most abundant. In 2012, *N. kadiakensis* abundance increased in spring and summer, but decreased in fall from 2011. After reaching the highest spring abundance on record in 2008, abundance decreased from 2009 through 2011, before increasing slightly in 2012. In 2012, summer abundance increased for the third year in a row, and was above the summer mean for all years. After increasing sharply in 2011 to the highest level since 2002, fall abundance decreased again in 2012. In 2012, peak densities occurred in May in Carquinez Strait and Suisun Bay (3 m^{-3}), and in July in eastern Suisun Bay (4 m^{-3}). Since the late 1990s, *N. kadiakensis* has extended its range into lower salinity water at the confluence of the Sacramento and San Joaquin Rivers, leading to the hypothesis that some of the upper-estuary specimens may be a second species, *N. japonica*. No physical characteristics have been published to separate these 2 species to date.

Table 1B Seasonal abundance of the most common mysid species (mean catch*m^{-3}) from the macrozooplankton net. Abundances for *Neomysis kadiakensis* and *Alienacanthomysis macropsis* were not reported until 1996 and 1995 respectively, because they were not consistently enumerated in samples until the mid-1990s.

Year	*Neomysis kadiakensis*			*Alienacanthomysis macropsis*		
	Spring	*Summer*	*Fall*	*Spring*	*Summer*	*Fall*
1995				0.000	0.000	0.004
1996	0.032	0.001	0.017	< 0.001	0.000	0.003
1997	0.011	0.011	0.385	0.006	0.000	0.004
1998	0.108	0.041	0.006	0.005	0.000	0.008
1999	0.037	0.007	0.075	0.014	0.000	0.001
2000	0.074	0.165	0.465	0.003	0.000	0.001
2001	0.285	0.351	0.143	0.013	0.001	0.001
2002	0.209	0.254	0.753	0.005	0.000	0.002
2003	0.314	0.209	0.166	0.038	0.000	0.003
2004	0.129	0.106	0.170	0.001	0.000	0.001
2005	0.173	0.104	0.077	0.003	0.000	0.004
2006	0.071	0.727	0.051	0.001	0.000	0.001
2007	0.176	0.306	0.122	0.004	< 0.001	0.025
2008	1.359	0.820	0.154	0.027	< 0.001	0.155
2009	0.418	0.240	0.128	0.064	0.003	0.096
2010	0.177	0.280	0.081	0.090	0.002	0.183
2011	0.142	0.322	0.235	0.040	0.002	0.079
2012	0.215	0.485	0.133	0.144	0.001	0.039
Average:	0.231	0.260	0.186	0.025	0.001	0.034

Alienacanthomysis macropsis is a native brackish-water mysid usually found in San Pablo Bay and Carquinez Strait that began to be consistently enumerated by the study in 1995. *A. macropsis* has never been common in the sampling area, and therefore indices were not reported until 2007. Since 2009, *A. macropsis* abundance surpassed *N. kadiakensis* and became the second most abundant mysid in the upper estuary across all stations and surveys, although it remained a minor component of the mysid community due to high *H. longirostris* abundance. In 2012, spring *A. macropsis* abundance increased from 2011 to the highest spring abundance on record (Table 1). After reaching the highest summer abundance on record in 2009, *A. macropsis* abundance decreased slightly in 2010 and remained steady in 2011, before decreasing again in 2012. In 2010, fall abundance was the highest on record, and although abundance decreased in 2011 and 2012 it remained above the study-period fall mean. In 2012, *A. macropsis* was most abundant from January through April in San Pablo Bay and Carquinez Strait, and in January in Suisun Bay. The highest densities occurred in February (9 m^{-3}) and March (16 m^{-3}) in San Pablo Bay at a station near the mouth of the Petaluma River.

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Delta Smelt Captive Refuge Population Update 2013

Tewdros Ghebremariam (FCCL), tghebremariam@ucdavis.edu, Amanda Finger (GVL), Meredith Nagel (FCCL) , Luke Ellison (FCCL), Galen Tigan (FCCL), Bernie May (GVL), Joan Lindberg (FCCL)

Introduction

In a response to the rapid decline and threat of extinction of the Delta Smelt (*Hypomesus transpacificus*) population in the wild, a refuge population was initiated in 2008 at the University of California, Davis (UC Davis) Fish Conservation & Culture Laboratory (FCCL) located in Byron, CA. The refuge population constitutes a safeguard in the event of species extinction in the wild, with an additional, smaller population maintained at the Livingston Stone National Fish Hatchery, to guard against catastrophic loss. In collaboration with the Genomic Variation Laboratory (GVL) of UC Davis, the refuge population is genetically managed and monitored, with the aim of maintaining a captive population that is genetically similar to the wild population. These goals are achieved through the minimization of inbreeding, yearly incorporation of wild fish into the brood stock, and maximizing overall population genetic diversity using the existing aquaculture facilities at FCCL (Fisch et al. 2009). In addition, the program provides fish of all life stages for research activities.

Fish handling, rearing techniques, and facilities for the refuge population were similar to previous years (Fisch et al. 2009, 2010, Lindberg et al. 2013 and Nagel et al. 2013). Throughout the spring spawning season, a sub-sample of mature fish is identified with small alphanumeric tags and simultaneously a tiny tissue sample (fin-clip) is preserved. Tagged fish create the brood stock pool from which select pair crosses (one female and one male) are made. Fin-clips are sent to the GVL to collect molecular data for pedigree reconstruction and relatedness estimation. Tagged females are checked two times per week throughout the spawning season. Females with mature eggs are identified by tag and a list is sent to the GVL, they select the best male to pair with each ripe female (based on molecular data). Identified males are found through parentage analysis and minimizing mean kinship (Fisch et al. 2009, 2013) and the pairs are spawned in vitro that same day at the FCCL. Our target refuge population size is 500 individuals, or 250 recommended single pair crosses (one male one female) annually, each one producing a full-sibling family or group (FSG). To achieve the target population within the space and labor constraints of the FCCL, multiple FSGs are reared together. Typically eight FSGs, usually with 750 live eggs from each FSG, spawned within 10 days of each other are combined together, making a multi-family group (MFG). Each MFG is reared together through egg incubation, larval, juvenile, and adult life-stages in progressively bigger tanks. Tank capacity (40 tanks per life stage) determines the number of families reared together and the total number of multifamily groups we can hold. 32-36 MFGs are reared each year at the FCCL (Lindberg et al. 2013).

Over several years we have been monitoring and making adjustments to the Delta Smelt breeding program. The founder generation (F_0) of the captive refuge population consisted of 164 pair crosses from wild-caught individuals, and has progressed to the sixth generation (F_6) in 2013. The F_6 is the result of 310 pair crosses, 261 of which were successful and will be the parents for the F_7 generation. The following summary of the Delta Smelt captive refuge population shows the changes made in 2013 with respect to tagging methods and family recovery (the number of FSGs created in 2012 where one or more offspring survived to be tagged and potentially spawned in 2013). We also discuss the effects of "early termination" of the spawning season and wild fish incorporation to family recovery.

Tagging

Effective tagging is integral in genetic management and is the first step in family recovery because it allows identification of individual fish, and the ability to make genetically recommended pair crosses. The process of FSG recovery begins each year by creating the tagged brood stock pool, a sub-population of mature adult fish. A total of 2,217 individuals from the F_5 generation and wild were tagged from January 24 through April 26, 2013. Tagging continued weekly for both ripe cultured and wild fish. A tagging strategy of 1:2 female to male ratio was adopted this year. The logic behind this decision is that males are always ripe, while females only come ripe for a limited time. Tagging more males would create a more diverse gene pool for mating and potentially improve recovery of families. Tagging more males continued through March, but by mid-March more females were needed to pair with wild males before the season ended. Tagging effort is progressively directed toward the fish hatched later in the previous season (larger MFG numbers). Early abundance of males proved useful, while the overall number of males and females tagged was 1,157 and 1,060 respectively, or nearly 1:1, with the male:female tagging ratio changing between months and MFGs (Figure 1).

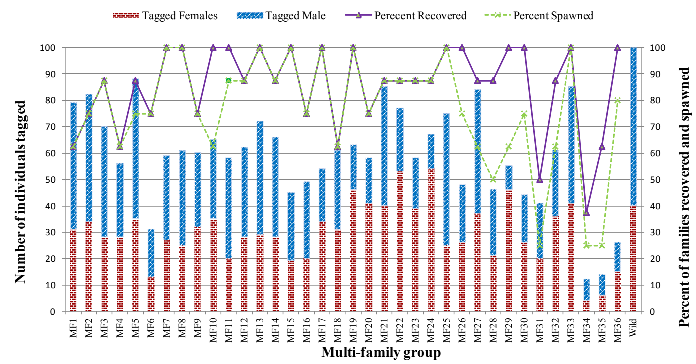

Figure 1 Overview of Delta Smelt tagging, recovery and spawning of multifamily groups (MFGs) created during the 2012 spawning season (F_5). Shown are the male:female tagging ratio, percent full-sibling groups (FSGs) recovered and spawned to create F_6 in the 2013 spawning season.

Collection, Spawning, and Recovery

Wild fish are collected annually to supplement the refuge population. Prior to the spawning season, (late December and early January), 100 fish were collected from lower Sacramento River near Sherman Island and the Sacramento Deep Water Ship Channel (about eight miles north of Rio Vista). All collected fish (40 females and 60 males) were tagged and added to the wild brood stock pool with 83% supplementing the refuge population during the season. Spawning occurred from February 5 to May 17, 2013, with a total of 310 pair crosses were made in the season; 221 cultured x cultured fish, 85 cultured x wild, and four wild x wild pairs. The final number of successful crosses made was 261.

The ability to recover individuals from each FSG is crucial for successfully maintaining the genetic diversity of the refuge population, and serves to document deviations from the founder population (Fisch et al. 2009). A pair cross (or FSG) is considered "recovered" if one or more tagged offspring are identified by genetic analysis in the following year. A MFG has 100% recovery when at least one individual from each of the FSGs (eight per MFG) have been identified in the brood stock pool. During the previous 2012 spawning season, 36 MFGs comprised of 281 FSGs were created, and the spawning season was extended through the end of May due to technical problems experienced earlier in the season. Some FSGs are recovered into the brood stock pool but not spawned. Figure 1 shows a summary of MFG spawning and recovery.

In 2013, 261 successful pair crosses were obtained from 522 F_5 individuals and wild fish and 239 of the 281 FSGs (85%, Figure 2) created in 2012 were represented in the brood stock pool. The proportion is similar to previous years.

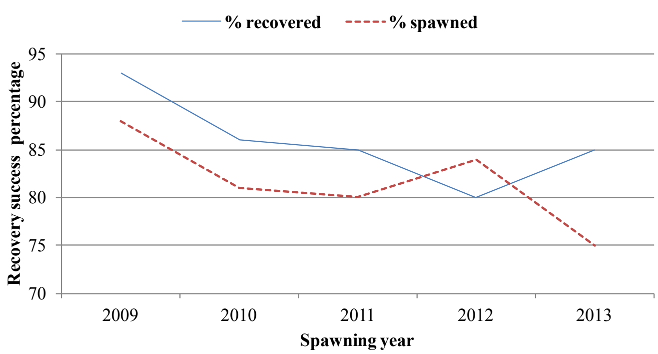

Figure 2 Recovery (percentage of full-sibling groups (FSGs) represented in the brood stock pool) and spawning (percentage of FSGs successfully spawned, creating the next generation) progress of Delta Smelt refuge population 2009-2013

In 2013, 12 FSGs from the F_5 generation were not desirable (being over represented in the population). Excluding these twelve FSGs, 202 FSGs (75.0%) from F_5 generation were successfully spawned and created the F_6 generation. The recovery of FSG from F_5 was lower compared to the previous year (84.0 %) of the F_4 generation. Lower recovery in 2013 stemmed from the number of supplemental wild fish, mating methods, and termination of the spawning season in mid-May.

Since the fall of 2012 the FCCL was allowed to capture a total of 100 wild fish. Our previous permit had slightly different language, we were allowed to take a total of 100 fish, but we could not have more than 50 live fish within 72 hours following capture and transport. The new permit language benefits the refuge population as more wild animals are incorporated in the refuge population. One should expect the recovery of the previous year's parents since 2012 to be a smaller percentage of the total recovery, with higher incorporation of wild fish. We favor incorporation of the wild fish into the refuge population to maximize genetic diversity, because wild fish are assumed to be unrelated to the cultured stock (Fisch et al. 2013). Ideally all FSGs from the previous generation would be crossed into each succeeding year's population, in addition to all wild fish. However this would lead to the creation of more FSGs than the roughly 250+ that the facility can maintain annually. A tradeoff between wild stock, which is favored, and cultured stock explains the lower recovery of F_5 FSGs that were spawned in 2013, but it keeps the cultured stock more diverse.

The incorporation of wild fish into the refuge population has its own concerns. Usually mating in the refuge population occurs between two cultured fish. A wild parent supplemented into the refuge population is either mated with another wild fish (wild x wild crosses) or a cultured fish from the refuge population (wild x cultured crosses). We have observed differences in recovery success between crosses with 1 or 2 wild parents and those with two cultured parents. Based on data from 4 spawning seasons of the refuge population in which 51 wild x wild, 100 wild x cultured and about 1,000 cultured x cultured crosses were made, the recovery and spawning success of wild x wild crosses is lower than the recovery and spawning success of wild x cultured and cultured x cultured crosses (Figure 3). Anecdotally, the age of parents did not increase recovery of wild crosses. Among four crosses made in 2012 between 2-year-old wild and 1-year-old wild fish in an effort to recover lost families due to disease (Nagel et al. 2013), only one of the four crosses was recovered in 2013. Importantly, the differences in recovery between wild x wild and cultured crosses may be the result of domestication selection, where Delta Smelt are increasingly adapted to the hatchery environment (Mark et al. 2012). Perhaps recovery would have been better if all wild x wild fish were reared together in the same tank, instead of rearing the wild offspring with cultured x cultured offspring. Nevertheless, recognizing the recovery and survival differences between cultured and wild crosses, we favored making crosses where only one parent was wild; we made 75 wild x cultured and four wild x wild crosses compared to eight wild x cultured and 20 wild x wild crosses made in 2012.

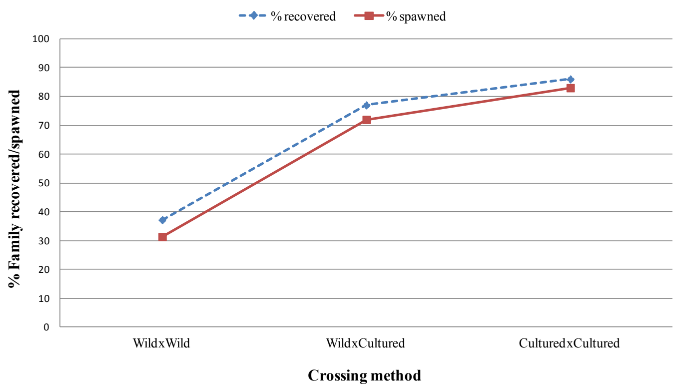

Figure 3 Delta Smelt families' recovery (% represented in the brood stock pool) and spawning (% spawned successfully) success of wild and cultured population and their crosses (average for 2009-2012 spawning season)

The wild population of Delta Smelt is believed to spawn primarily in March and April (Bennett 2005), and the Spring Kodiak Trawl survey of wild Delta Smelt also shows that few females are caught and most of them are spent by the beginning of May (CDFW 2013). Consequently, we would like to spawn the majority of refuge fish within this time frame. By terminating spawning two weeks earlier this year than last year (mid-May in 2013 vs late-May in 2012; Figure 4) we anticipated limiting the poor-recovery-effect of late-hatch fish. The younger fish from late spawns are small and slow to mature, making them harder to spawn as adults, though maturation and spawning may be improved by raising the ambient temperature of their rearing tanks (Nagel et al. 2013).

In parallel with the usual recovery process in a given season, various rearing methods have been tested to improve recovery of families. Specifically, the effect of splitting MFGs and rearing four vs the normal eight families at a higher representation rate (1,000 eggs/FSG, and 4,000 eggs total vs 6,000 eggs normally), have been through larval and juvenile stages but thus far the results are not conclusive. Rearing trials will continue next year.

Genetic Monitoring

Genetic diversity analysis of the F_5 refuge population, was accomplished by using 12 microsatellite loci to estimate standard genetic indices including the number of alleles (A), allelic richness (A_r), expected (H_e), and observed heterozygosity (H_o) for all spawned wild and cultured fish. For the F_5 generation, an average of 506 alleles was scored across the 12 genotyped loci. Allelic richness ranged from 7 to 32.80. The mean H_e was 0.85 and the mean H_o was 0.83 (Table 1). For most loci, allelic richness of this group of fish was higher than the average A_r over all generations spawned to date, indicating that incorporating more wild fish this year may have increased genetic diversity of the refuge population. To examine genetic differentiation between generations, we calculated pairwise FST values (a measure of genetic differentiation ranging between 0, not differentiated, and 1, completely differentiated) using the software Arlequin (Excoffier et al. 2010) between F_0-F_5 generations, spawned cultured fish only, and spawned wild fish only (Table 2). The only significant values for comparisons between 2013 spawning fish (wild and cultured fish combined) after a Bonferroni correction were those between the F_5 and F_0 (Table 2). Importantly, the FST value between wild fish and cultured fish spawned this year was very low (FST $<$ 0.001) and not significant ($P =$ 0.523). These results suggest we are successfully maintaining a refuge population similar to the wild population at neutral loci, though we cannot rule out differentiation between the wild and captive populations at other markers in the genome.

Conclusion

This year we created the sixth generation of the Delta Smelt refuge population by successfully crossing 522 adult fish. Small changes are made each year in an effort to improve the breeding program. In 2013, the overall recovery of families was good (85%), as was successfully spawned (75%), despite a large number of wild fish incorporated and early termination of the spawning season. In accordance with the objective of Delta Smelt captive population breeding program, the genetic integrity of the Delta Smelt refuge population, as determined through neutral loci, has been maintained and will continue through the next spawning season.

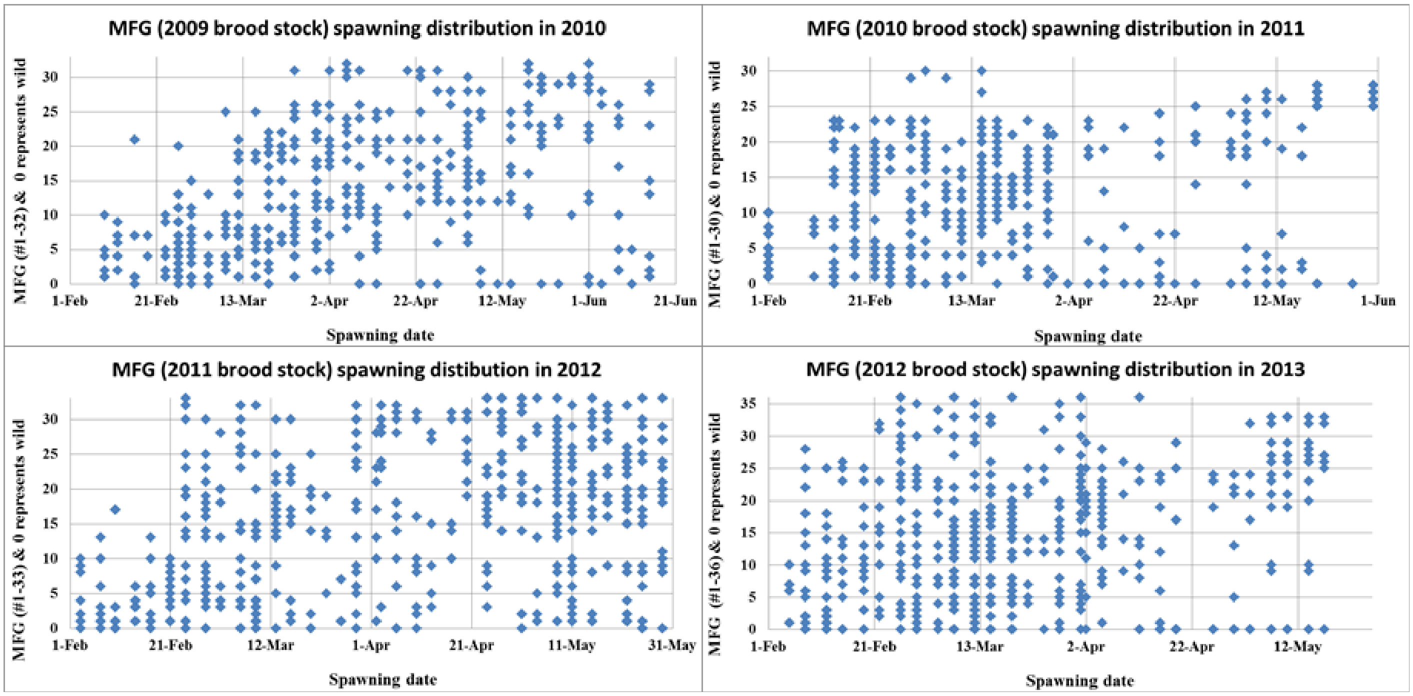

Figure 4 Spawning distribution of Delta Smelt refuge population and interannual spawning duration (2010-2013) by date and multifamily group number (MFG: 1-36). Each dot in a given year represents the date when an individual of a given MFG spawns. MFGs in y-axis included progressively from lower numbers (spawned early in the year before) to higher numbers (spawned late in the year before); the value 0 in y-axis refers to wild fish incorporated to the population in a given season.

Table 1 Genetic indices measured for the group of wild and cultured Delta Smelt spawned in 2013. For each of the 12 microsatellite loci, number of individuals genotyped (N), number of alleles (A), allelic richness (A_r), average allelic richness over all generations, observed heterozygosity (Ho), and expected heterozygosity (He) is shown.

F_5 generation (including wild and cultured fish)						
Locus	*N*	*Total A*	*Total A_r (930 genes)*	*Average A_r over generations*	*H_o*	*H_e*
Htr103	481	18.00	18.00	17.84	0.88	0.88
Htr104	518	10.00	9.69	7.80	0.48	0.48
Htr109	519	17.00	16.99	15.76	0.90	0.88
Htr114	506	29.00	28.84	27.36	0.89	0.95
Htr115	514	32.00	31.50	26.63	0.87	0.93
Htr116	512	7.00	7.00	6.91	0.55	0.54
Htr117	465	23.00	23.00	18.86	0.91	0.91
Htr119	512	32.00	31.99	30.64	0.95	0.95
Htr120	516	16.00	15.80	14.46	0.84	0.83
Htr126	514	30.00	29.80	27.20	0.85	0.94
Htr127	517	32.00	31.80	29.58	0.92	0.96
Htr131	497	33.00	32.80	29.03	0.96	0.95
Average	506	23.25	23.10	21.23	0.83	0.85

Table 2 F_{ST} values for each generation of Delta Smelt shown below the diagonal and associated P-values shown above the diagonal. Bold values indicate significance value after Bonferroni correction.

	F_0	*F_1*	*F_2*	*F_3*	*F_4*	*F_5 all*	*F_5 cult.*	*BY 2012 wild*
F_0	-	0.991	0.018	0.991	0.009	0.000	0.000	0.009
F_1	-0.008	-	0.991	0.991	0.991	0.991	0.991	0.991
F_2	<0.001	<0.001	-	0.991	0.505	0.027	0.009	0.712
F_3	-0.001	-0.004	-0.004	-	0.991	0.991	0.991	0.991
F_4	0.001	-0.006	0.000	-0.003	-	0.568	0.532	0.586
F_5 all	0.002	-0.007	<0.001	-0.002	0.000	-	0.991	0.856
F_5 cult.	0.002	-0.007	<0.001	-0.002	<0.001	-0.001	-	0.523
BY 2012 wild	0.002	-0.008	-0.001	-0.003	0.000	0.000	<0.001	-

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3500 Industrial Blvd.
West Sacramento, CA 95691

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